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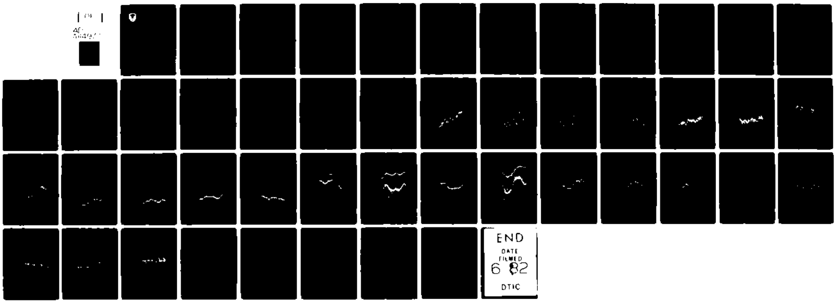

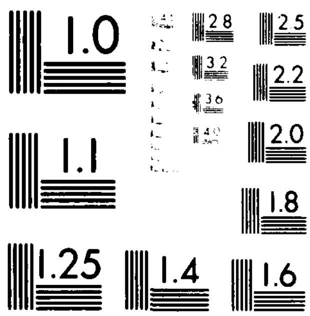
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TECOM No. 7-CO-RD2-DP1-006
DPG Document No. DPG-FR-82-703

METHODOLOGY INVESTIGATION
FINAL REPORT
PERFORMANCE OF TEMPERATURE/ DEW POINT INSTRUMENTS

BY

CHRISTOPHER BILTOFT

APRIL 1982

US ARMY DUGWAY PROVING GROUND
DUGWAY, UT 84022

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TECOM No. 7-CO-RD2-DP1-006	2. GOVT ACCESSION NO. AD-A114977	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Methodology Investigation, Final Report Performance of Temperature/Dew Point Instruments		5. TYPE OF REPORT & PERIOD COVERED Methodology Report
		6. PERFORMING ORG. REPORT NUMBER DPG-FR-82-703
7. AUTHOR(s) Christopher A. Biltoft		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Dugway Proving Ground ATTN: STEDP-MT-DA-M Dugway, UT 84022		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 3152510302
11. CONTROLLING OFFICE NAME AND ADDRESS Commander US Army Dugway Proving Ground Dugway, UT 84022		12. REPORT DATE April 1982
		13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Temperature/dew point systems	thermistor	filt.
dewcell	thermometer	
optical condensation hygrometer	lag coefficient	
lithium chloride hygrometer	noise	
thermoelectric (Peltier) cooler	calibration drift	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of field trials was conducted to assess the performance of temperature/dew point systems used at the US Army Dugway Proving Ground, UT. Data quality was degraded by noise, calibration drift, and exposure to adverse ambient conditions. Improved noise reduction procedures, particularly improved computer program noise filters, are needed. Calibration drift can be detected by comparison with a standard in the field or by deployment of instruments in pairs at one level. Exposure to adverse ambient conditions can be avoided by proper test planning and execution.

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ABSTRACT

A series of field trials was conducted to assess the performance of temperature/dew point systems used at the US Army Dugway Proving Ground, UT. Data quality were degraded by noise, calibration drift, and exposure to adverse ambient conditions. Improved noise reduction procedures, particularly improved computer program noise filters, are needed. Calibration drift can be detected by comparison with a standard in the field or by deployment of instruments in pairs at one level. Exposure to adverse ambient conditions can be avoided by proper test planning and execution.

Operated under favorable ambient conditions, dewcell hygrometers provide useful average dew points where great accuracy is not required. Optical condensation hygrometers responded faster and more accurately than the dewcell hygrometers. However, the temperature sensing system in the optical condensation hygrometers was inaccurate and unreliable. The thermistor temperature sensing system performed well during this test, but the data were severely damped.

SECTION I. SUMMARY

1. BACKGROUND. Tests conducted at US Army Dugway Proving Ground (DPG), UT which involve droplet growth or evaporation, refractive index, or require characterization of the diffusion process, need accurate temperature and dew point data. Although a number of temperature and dew point measurement systems are used at DPG, the performance of these instruments under field conditions has received little attention. Consequently, a requirement exists to evaluate the capabilities and performance of temperature and dew point systems operated under field conditions.

2. OBJECTIVES. The objectives of this report are to evaluate the performance of DPG temperature/dew point instruments operated under field conditions, and to determine the factors which adversely affect temperature/dew point data quality.

3. DETAILS OF INVESTIGATION.

a. Site Description. In May and June 1981, trials with several temperature/dew point systems (operating concurrently) were conducted in conjunction with other tests at the Horizontal Grid, DPG. The Horizontal Grid is near the southeastern edge of the Great Salt Lake Desert. Terrain in this area is quite flat, sloping down gently to the northwest. Average plain elevation is 1300 m. The largest obstacle to airflow, Granite Mountain, 12 km southwest of the grid, rises 850 m above the terrain. Vegetation includes shadscale, sagebrush, and gray molly growing in well spaced clumps up to 1 m tall. Roughness is approximately 2.3 cm (Reference 1). Additional information on terrain, climate, and vegetation is in Reference 2. Spring rains kept the desert surface fairly moist during these trials.

b. Meteorological Conditions. Three one-hour data collection periods were chosen to represent spring meteorological conditions at DPG. Table 1 includes averaged wind conditions for the three trials. The data are given in four successive 15-minute averages (A, B, C, D).

Weather for Trial 1 on 5 May 1981, 15:54:31 to 16:54:30 GMT, included a scattered altocumulus layer at 7000 ft (2100 m) above ground level (AGL), with an overcast cirrus layer at 20,000 ft (6000 m) AGL. Light precipitation falling out of the clouds, but not reaching the ground (virga) was reported in all sky quadrants. A cold front was stalled in Nevada and Oregon, with a weak low pressure system forming along the Utah-Nevada border. A weak surface pressure gradient and differential surface heating produced light, variable westerly winds, averaging less than 1 m/sec. Moderate insolation occurred through the cloud layers, and the Pasquill Stability Category was B. The ground was moist.

Prefrontal conditions characterized the weather for Trial 2 on 19 May 1981, 19:05:00 to 20:05:02 GMT. A 500-millibar (mb) ridge was centered over the Dakotas, with a deep low pressure trough along the coast of California. The surface weather analysis depicted a frontal system along the Utah-Nevada border. A low pressure system was also developing over central Utah. Weather at DPG was characterized by scattered to broken altocumulus layers at 7000 ft (2100 m), 12,000 ft (3600 m), and an overcast layer at 15,000 ft (4500 m) AGL. There was a strong pressure gradient across DPG. Gusty prefrontal

Table 1. Wind Measurements at the DPG Horizontal Grid 2-M Level.

Trial	Horizontal Wind Speed (m/sec)	Horizontal Wind Direction (degrees)	Vertical Wind Angle (degrees)
1A	0.60 (0.26)	246 (39.59)	(10.99)
1B	0.63 (0.23)	276 (22.28)	(8.87)
1C	0.64 (0.29)	316 (54.54)	(12.94)
1D	0.94 (0.42)	312 (70.44)	(8.39)
2A	8.62 (1.68)	181 (8.13)	(5.68)
2B	10.11 (1.74)	171 (8.36)	(5.28)
2C	9.94 (1.68)	165 (10.42)	(5.14)
2D	9.49 (1.68)	161 (8.20)	(5.36)
3A	1.26 (0.80)	221 (82.59)	(14.90)
3B	2.26 (0.84)	321 (33.96)	(11.08)
3C	1.41 (0.82)	009 (62.52)	(18.61)
3D	1.54 (0.70)	162 (48.66)	(16.67)

Presented in successive 15-minute means (A, B, C, D), with standard deviations in parenthesis.

southerly winds were recorded. Insolation was weak. The weak insolation and strong surface winds produced Pasquill Category D stability. The ground was moist.

Trial 3 on 1 June 1981, 17:21:30 to 18:21:29 GMT, had only weak synoptic influence. There was a weak 500-mb ridge over Nevada and Utah, with a major low center south off the Aleutian Islands. A weak surface front was just off the coast of Oregon. The pressure gradient over DPG was light, with a thermal low over Nevada and a weak high center over northeastern Arizona. Thin, scattered layers of clouds occurred at 7000 ft (2100 m) and 15,000 ft (4500 m) AGL. A few cumulus clouds were forming over the distant mountains. The strong solar insolation and light, variable winds produced Pasquill Category A stability. The ground was moist.

c. Instruments. Temperature/dew point systems used at DPG include General Eastern (GE) optical condensation hygrometers, and EG&G optical condensation hygrometers. The Climet CI-16 lithium chloride (LiCl) dewcell is also used for dew point measurement. Temperature information is also collected using the Climet CI-60 translator with a thermistor element mounted in an aspirated horn. These instruments were mounted in a cluster 2.0 to 2.5 m AGL on a 32-m rectangular walk-up tower. Anemometers and bi-directional vanes for wind measurements were placed at several additional levels on the tower. Appendix B contains detailed descriptions of the instruments.

d. Data Collection Procedure. Before placement in the field, the instruments were calibrated and then operated in an environmental chamber for five days. The chamber consisted of a sealed instrument shelter, containing a regulated heat source and hygroscopic salts for humidity control. Data from

instruments in the chamber were recorded on chart recorders. The CI-60 system was not tested in the chamber because it was needed in the field for test support. The chamber test was conducted from 5 to 9 March 1981.

Following the chamber tests, the instruments were mounted on the Horizontal Grid 32-m tower. The GE and CI-16 instruments were located on a boom approximately 2.5 m above ground level, extending from the northwest corner of the tower, pointing to the west. The EG&G instrument was located just below the boom, oriented to the northwest. With its 168-cm aspirator length, it was sampling air from approximately the same source as the instruments on the boom. The CI-60 instrument was located on the northeast corner of the tower, pointing north, at a horizontal distance of 2.0 m from the rest of the instruments. With the exception of the CI-60, the instruments were substantially shaded by the tower during the mornings and early afternoons when data were collected. The CI-60 was exposed to direct solar radiation during Trials 1 and 3, but was well shaded by clouds on Trial 2. The instruments were cleaned and serviced before each trial. Data were collected for one-hour periods.

Data channels for the tower instruments were wired into a Teledyne Model 704 Encoder. The data were then transmitted via "S" band radio frequency in a pulse code modulation (PCM) format to a PCM data collection van. In the van, the signal was recorded on analog tape. The analog tape was then run through and EMR 7071 Decommutation System, where the demodulated signal was recorded on digital tape.

The data collection rate (frame rate) was 200 per second on the PCM main frame, and 5 per second on the subcommutator (subcom). The GE No. 2 temperature, and the GE No. 1 and GE No. 2 dew point channels were located on the main frame. The remaining data channels were on the subcom. All data were averaged for one-second periods before printout by the Hewlett-Packard 3000 computer.

Resolution of the collected data was limited by the range of the instruments, the system output voltage and the data channel voltage. The CI-60 had a range of 0 - 100°F (-18 to +38°C) into a 0.0 - 1.4 volt output. This output was wired into a 0.0 - 2.0 volt, 1024-bit channel. The channel output was therefore limited to 717 bits, with a resolution of 0.14°F (0.08°C) per bit. The other instruments had a 5.0-volt output range wired into 5.0 volt channels. Range on the GE instruments was -100 to +100°F (-73 to +38°C), for a 0.19°F (0.1°C) resolution per bit. The EG&G had a range of ±50°C, for a resolution of 0.1°C per bit.

4. RESULTS.

a. Environmental Chamber. The objective of the chamber test was to compare instrument tracking and response in a steady, controlled environment. Dew point measurements were made on the fifth day of operation in the chamber. The 9 March chart readings indicated that the optical condensation hygrometers produced dew points in agreement to within 0.7°C. Consistently higher readings were obtained on the GE No. 2 instruments. The GE No. 2 also produced high frequency oscillations of greater amplitude than those observed by the other instruments. LiCl systems were concurrently checked in the chamber. The CI No. 1 displayed a tendency to drift off calibration, giving dew point readings one degree below the average. The other LiCl system provided dew points in close agreement with the instrument group average.

b. Field Trials. Table 2 contains 15-minute averaged 2-m temperature data. Instrument reading variations for each 15-minute period can be observed across each row of data. The greatest range in temperatures for Trials 1 and 2 occurred between the GE No. 1 and GE No. 2 instruments. For Trial 1, the average range between these two instruments was 0.91°C, which increased to 1.72°C for Trial 2. No comparable data are available for Trial 3 because GE No. 2 was moved to the 32-m position before that trial. In spite of its exposure to direct solar radiation, the CI-60 system consistently produced average temperatures within the range of the GE No. 1 and GE No. 2 instruments.

Table 2. Temperatures (°C) Measured at the DPG Horizontal Grid.

Trial	GE No. 1	GE No. 2	EG&G No. 1	CI-60
1A	13.88 (0.27)	14.64 (0.35)	13.89 (0.22)	14.15 (0.15)
1B	14.29 (0.28)	15.27 (0.12)	14.36 (0.32)	14.70 (0.30)
1C	15.06 (0.42)	16.00 (0.27)	15.25 (0.39)	15.67 (0.36)
1D	15.75 (0.21)	16.51 (0.53)	16.00 (0.21)	16.70 (0.11)
2A	20.52 (0.15)	22.16 (0.57)	--[a]	21.24 (0.12)
2B	21.08 (0.25)	22.87 (1.09)	--	21.53 (0.04)
2C	21.20 (0.28)	22.94 (1.14)	--	21.60 (0.09)
2D	21.24 (0.27)	22.95 (1.15)	--	21.61 (0.29)
3A	22.06 (0.33)	--	--	23.90 (0.24)
3B	22.56 (0.22)	--	--	22.55 (0.15)
3C	22.71 (0.36)	--	--	22.63 (0.46)
3D	23.34 (0.14)	--	--	23.90 (0.24)

Tower 2-m level presented in four successive 15-minute means (A, B, C, D) with standard deviations in parenthesis.
[a]No Data.

Table 3 presents 15-minute averaged dew point means and standard deviations. Unlike their corresponding temperature systems, the GE dew point systems appeared to track closely together. The average difference in readings between the GE No. 1 and GE No. 2 was 0.33°C for Trial 1 and 0.30°C for Trial 2. The average difference between CI No. 1 and CI No. 2 was 0.12°C for Trial 1, 0.54°C for Trial 2, and 0.70°C for Trial 3. These data indicate that at least one of the dewcells was drifting off calibration between trials.

Table 4 presents Trial 3 temperature and dew point data, measured at the tower 32-m level using GE No. 2. The GE No. 2 dew points read higher than the corresponding dew points at the 2-m level (Table 3), indicating a humidity inversion. Higher dew points usually occur near the surface, except when the surface is extremely dry or during nocturnal humidity inversions. Spring rains kept the ground moist during Trial 3. Therefore, the implied humidity inversion is not real, but is a result of GE No. 2 reading higher than GE No. 1, as it did in Trial 1.

Table 3. Dew Points (°C) Measured at the DPG Horizontal Grid.

Trial	GE No. 1	GE No. 2	EG&G No. 1	CI No. 1	CI No. 2
1A	0.69 (0.24)	0.99 (0.28)	0.54 (0.23)	0.44 (0.13)	0.48 (0.11)
1B	0.72 (0.25)	1.05 (0.31)	0.59 (0.23)	0.58 (0.12)	0.62 (0.09)
1C	0.26 (0.42)	0.58 (0.48)	0.12 (0.45)	0.25 (0.23)	0.48 (0.17)
1D	0.14 (0.66)	0.51 (0.72)	0.07 (0.69)	-0.01 (0.48)	0.14 (0.31)
2A	-1.05 (0.27)	-1.43 (0.32)	--[a]	-0.49 (0.12)	-1.07 (0.21)
2B	-1.00 (0.17)	-1.22 (0.23)	--	-0.56 (0.07)	-1.06 (0.11)
2C	-1.26 (0.25)	-1.24 (0.30)	--	-0.68 (0.13)	-1.26 (0.17)
2D	-1.04 (0.28)	-1.24 (0.32)	--	-0.64 (0.15)	-1.13 (0.21)
3A	4.56 (0.11)	--	--	4.60 (0.09)	3.90 (0.16)
3B	4.55 (0.12)	--	--	4.57 (0.08)	3.82 (0.13)
3C	4.53 (0.28)	--	--	4.47 (0.12)	3.83 (0.20)
3D	4.70 (0.25)	--	--	4.76 (0.06)	4.05 (0.08)

Tower 2-m level presented in four successive 15-minute means (A, B, C, D) with standard deviations in parenthesis.
[a]No data.

Table 4. Temperature and Dew Point Measurements (°C) at the DPG Horizontal Grid Tower 32-M Level (GE No. 2 Instrument).

Trial	Temperature	Dew Point
3A	21.06 (0.56)	4.87 (0.29)
3B	21.43 (1.31)	4.81 (0.40)
3C	21.52 (0.22)	4.83 (0.22)
3D	22.04 (0.21)	4.94 (0.11)

Standard deviation data in Tables 1 through 4 are computed based on the assumptions that the one-second data points are distributed about a constant mean value, and that the distribution of these points is normal. Micrometeorological data frequently violate these assumptions. Temperature and wind data follow trends with time as the atmosphere adjusts to diabatic heating or cooling. Standard deviation data are useful because unusually large standard deviations often indicate a problem with the data. Usually, a temperature standard deviation of 0.5°C or more indicates a significant change in temperature during the sampling period, or the presence of a large noise signal. In either case, the representativeness of the data is questionable. The large standard deviations in the GE No. 2 temperature data (Tables 2 and 4) are due to noise. Conversely, the large dew point standard deviation in Trial 1D (Table 3) are due to a significant change in dew point during that portion of the trial (see Figure C.8). Trial 2, with less dominant diabatic effects, is an example of a favorable condition for representative mean and standard deviation computations.

5. ANALYSIS OF TRIAL PLOTS.

a. Plot Description. To supplement the means and standard deviations, the temperature and dew point data were plotted graphically versus time (Appendix C). Figures C.1 - C.24 depict temperature and dew point traces in four 15-minute increments for each trial. The 5 May trial is presented in Figures C.1 - C.8, the 19 May trial is covered by Figures C.9 - C.16, and the 1 June trial is given in Figures C.17 - C.24. The plots were prepared from one-second average data, with the time scale compressed by a factor of 10.

b. Temperature Plot Analysis. The temperature versus time plots for Trial 1 (Figures C.1 - C.4) display three distinct patterns. The GE No. 2 produced a pattern consisting of small amplitude, high frequency fluctuations superimposed on low frequencies of small amplitude. The CI-60 produced a severly truncated pattern, with a "stair step" trace interrupted infrequently by solitary spikes of small amplitude. The CI-60 plots are almost entirely free of the high frequency fluctuations present in the other plots. The low frequency portion of the CI-60 and GE No. 2 traces appear to track together, although the actual temperatures are offset by 0.5°C. The spikes on the GE No. 2 data are easily identified as noise.

The third temperature versus time plot pattern for Trial 1 is common to the GE No. 1 and the EG&G instruments. These temperature data (Figures C.1 - C.4), contain high frequency fluctuations of small amplitude superimposed on lower frequency fluctuations. These lower frequency fluctuations had periods of 10 - 100 seconds and amplitudes on the order of 0.5°C. The GE No. 1 and EG&G do not track with the CI-60 and GE No. 2 patterns. Further interpretation of these patterns requires consideration of instrument response (lag times).

The response of thermometers to a simple sine wave variation about a mean temperature is described in a Meteorological Office Handbook (Reference 3). For a harmonic period of "S" seconds and a lag coefficient of © seconds, response of instruments for various S/© ratios is provided in Table 5. Phase lag for the instrument is also presented in Table 5. Phase lag is the lag, in degrees, of instrument response to the phase of a sine wave input. Although atmospheric temperature changes are far more complicated than simple harmonic variations about a mean, the relationships in Table 5 provide a good approximation for most conditions.

Table 5. Response of Thermometers to Fluctuating Temperatures for Given S/© Ratios (BMO, 1969; Reference 3).

Ratio of period to lag coefficient (S/©)	0.2	0.4	0.6	0.8	1.0	2.0	4.0	6.0	10.0
Ratio of response to true amplitude	0.04	0.06	0.09	0.13	0.16	0.31	0.54	0.69	0.85
Phase lag (degrees)	88	86	85	83	81	72	58	46	32

Validity of the GE No. 1 and EG&G low frequency data can be evaluated using Table 5. Response of these systems is lagged, with θ = 60 seconds for the GE No. 1, and θ = 40 seconds for the EG&G. The variations observed in Figures C.1 - C.4 are typically 20 seconds in duration, with an amplitude of 0.5°C. The S/θ ratio is then 20/60 for the GE No. 1 and 20/40 for the EG&G; the most representative S/θ ratio in Table 5 is for S/θ = 0.4. This corresponds to a ratio of response to true amplitude of 0.06 and a phase lag of 86°. True air temperature variations of 8°C would be required to produce the observed 0.5°C amplitude response. It is unlikely that temperature variations of 8°C occurred during these trials. A likely conclusion is that the variations were due to noise.

Trial 1 temperature data can also be evaluated qualitatively by comparison of instrument response. Large temperature fluctuations observed by the GE No. 1 and EG&G units were not present in the CI-60 and GE No. 2 data. Also, the GE No. 1 and EG&G responses were sometimes in phase and sometimes out of phase, or uncorrelated. An uncorrelated response is characteristic of noise. The absence of similar fluctuations on Trials 2 and 3 provides further qualitative evidence of a transient noise problem on the GE No. 1 and EG&G temperature systems during Trial 1.

c. Dew Point Plot Analysis. Figures C.5 - C.8 are plots of dew point versus time for Trial 1. A salient feature of the dew point versus time plots is the magnitude of the optical condensation hygrometer dew point signal amplitude, which is frequently 0.5°C or greater. The 10- to 30-second periods of these dew point oscillations and the relatively fast response time of these instruments produce S/θ ratios of 10 or greater. This indicates that the instrument was able to respond to rapid dew point variations. Dew point plots from the three optical hygrometers also tracked together, providing qualitative evidence that the instruments were not simply responding to uncorrelated noise. Variation in the signal amplitudes was probably due to differences in the GAIN control settings.

The GE No. 2 instrument response on Trial 3 (Figures C.21 - C.24) is different from the other optical hygrometer dew point responses. Before this trial, the GE No. 2 had been moved to the tower's 32-m level. At this height, instrument response to dew point variations was considerably reduced. The absence of the sharp spiking characteristic at the 2-m level indicates that the instrument was responding to less abrupt changes in dew points at the 32-m level.

Response of the CI-16 systems, depicted as CI No. 1 and CI No. 2 on the dew point plots, is considerably more damped than the response of the optical hygrometers. The CI-16 response also exhibits considerably greater lag. The lag effect is illustrated clearly in Figure C.8, where the dew point rise which produced the major peak at 400 seconds in the optical hygrometer traces did not peak until 600 seconds on the CI-16 traces.

6. CONCLUSIONS. The temperature/dew point systems described above require frequent service. While operating in a dusty field environment, the optical hygrometers require manual cleaning of the mirror surface every two or three days. Self-cleaning mechanisms did not function adequately. LiCl systems also required weekly service, including a re-doped bobbin. In contrast, the CI-60 thermistor system appeared to operate satisfactorily without attention during the entire trial period.

Calibration drift degraded the performance of several instruments. Drift errors were most noticeable with the CI No. 2 dew point and the GE No. 2 temperature systems, both of which had drifted about 1°C off the mean instrument cluster reading by Trial 3. The optical hygrometer dew points did not drift significantly between Trials 1 and 2, although there was evidence of slight drift by Trial 3. No drift tendency occurred with the CI-60s during these trials.

The optical hygrometer temperature systems, particularly the GE No. 1 and EG&G units, did not perform satisfactorily during the trials. This equipment apparently suffers from noise interference when operated as part of a larger data collection setup. Also, the slow response of the platinum resistors, combined with the large thermal mass of the instruments, prevents the collection of accurate, responsive temperature data to compliment the cooled mirror dew point measurements.

The ability of optical hygrometers to track dew point data in a rapidly changing environment was demonstrated during these trials. The dew point systems tracked together well and held calibration between Trials 1 and 2. The humidity inversion of Trial 3 suggests a slight calibration drift. Occasional wild dew point oscillations which occurred while these instruments were deployed in the field signaled a need for cleaning the mirror. If operated with the required care, these instruments are able to provide reliable dew point readings over a wide range of temperatures and humidities.

Previous studies (References 4, 6) concluded that LiCl instruments are able to provide averaged dew points when operated during favorable weather conditions. These instruments should not be used during extremely low (-18°C, or below) temperatures, during very dry (less than 20 percent relative humidity), or very wet (dew, fog) conditions. Because of the dewcell adjustment process, Folland recommends that the data be averaged over 15-minute periods (Reference 4). Significant drift during these latest trials suggests a requirement for frequent checks on calibration drift.

The CI-60 system performed satisfactorily during the trials, requiring neither cleaning nor calibration adjustment. However, the severely truncated response showed that the system was not responding at the thermistor's 10-second lag. Excessive damping occurred somewhere in the system's electronics. Temperature shielding and aspiration were judged adequate because the CI-60 temperatures did not deviate from readings taken by the instruments which received more shade.

7. RECOMMENDATIONS. Degradation in temperature/dew point data quality is a function of noise, calibration drift, and exposure to adverse ambient conditions. Any electronic data collection system has a certain amount of noise. Faulty data channels, improper grounding, inductance from power cables, and proximity to signal-generating devices are examples of noise sources.

Because noise arises from a variety of sources, noise minimization should be continuously addressed through the duration of a project, from test design through final data processing. In the test design phase, grids should be designed so that sensitive instruments are isolated from extraneous noise sources. A poor test design may permit clusters of electronic gear on and

around a meteorological tower, and the consequent degradation of meteorological data. Care must also be taken during meteorological tower decoration to isolate data cables from power cables, to eliminate spurious noise from data channels, and to ensure proper grounding. Test grid checkout should include provision for the time, manpower, and equipment needed to perform data quality checks.

Present noise reduction procedures consist of capacitive suppression in circuit electronics. A capacitor, connected across the output leads, acts as a crude low-pass filter. The capacitor, along with a series resistor, also boosts impedance to match the requirments of the data system. Capacitance is increased until the desired level of signal suppression is achieved. The result is often excessive damping, as was found with the CI-60 temperature system. Further effort is needed to identify specific noise frequencies so that higher quality notch filters can be used to selectively suppress noise.

Noise reduction should also be addressed in data reduction programs. Meteorological data reduction programs are presently designed only for the rudimentary elimination of outliers or spikes in the data. Software filters can be designed for noise reduction with greater control and flexibility than is possible with electronic filters. Noise reduction with software is therefore a more desirable quality control strategy than extensive use of electronic noise suppression.

Calibration drift is another problem which has caused degradation in data quality. Field detection of calibration drift can be accomplished through comparison of instrument readings with a standard. The use of a nonelectronic standard, such as an Assmann psychrometer, is desirable. The disadvantages of psychrometric comparisons are that psychrometers lose accuracy at temperatures below freezing or at low humidities, and they have a slow response. An alternative check would be to use electronic instruments in pairs at one level on a meteorological tower. If these instruments track together, then they could serve as a standard for spot checks of instruments at other levels on the tower.

The final data quality degradation problem arises from instrument operation in an unfavorable environment. Adverse operating conditions include temperature extremes and caustic or dusty environments. This type of data quality degradation can be avoided by proper test planning and attention to instrument operation and maintenance.

SECTION II. APPENDICES

APPENDIX A. REFERENCES

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5. General Eastern Instruments Corporation, 1978: Selecting Humidity Instruments for Industrial Processes Handbook, General Eastern Instruments Corporation, 36 Maple Street, Watertown, MA 02172.

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APPENDIX B. INSTRUMENTATION

The sensor element of a LiCl (dewcell) hygrometer consists of an electric heating coil within a fabric bobbin coated with a dilute solution of LiCl. The principle of operation is based on reaching vapor pressure equilibrium between the vapor in the air and the hygroscopic LiCl surface. As the bobbin dries, its electrical resistance increases, which causes a reduction in current flow through the heating unit. The system goes through heating/cooling cycles until an equilibrium vapor pressure is reached. This equilibrium vapor pressure is uniquely related to a dew point temperature. General Eastern Instrument Corporation reported that sensor response is a function of the bobbin thermal mass, the flow of electrical current, and the flow rate of the surrounding air (Reference 5). Response lag is on the order of several minutes. General Eastern also reports that accuracies of ±2.0°F (±1.1°C) are possible with dewcells over a temperature range to +10 to +100°F (-12 to +38°C).

A major advantage to dewcell sensors is that they are not very sensitive to contamination. However, some care is needed in preserving LiCl coating integrity. Exposure to water or excessive contamination will ruin the coating. Once set into operation, this equipment should be run continuously, to prevent moisture accumulation from disturbing the LiCl coating.

Dewcell hygrometers have been used as standard equipment in several countries for many years. Folland described extensive trials of remote-indicating dewcell systems operating at field sites in Britain (Reference 4). Folland found that fluctuations recorded by the dewcells were exaggerated in comparison to those recorded by an aspirated psychrometer. The effects of these fluctuations were markedly reduced by averaging the dew point readings over 15-minute periods. The shielded dewcells were only slightly affected by wind speed and solar radiation, although corrections were required for variations in dewcell response at various relative humidities. Folland concluded that dewcell performance was superior to that of a psychrometer at temperatures below the freezing point, but inferior at high humdities, particularly in fog.

A second dewcell study was performed under lower temperatures by Henning in Germany (Reference 6). The LiCl hygrometer response was unreliable at temperatures below -18°C. Performance also declined markedly at relative humidities below 30 percent. Henning further concluded that precision greater than ±0.4°C is not feasible within normal operating range.

Although the Climet CI-16 dewcell system used at DPG is of different manufacture than the instruments used in the studies described above, operating principles are similar. Similar limitations would be applicable. For the DPG Horizontal Grid trials, the CI-16 temperature and dew point sequential scanning systems (CI-1, CI-2) were operated in the dew point mode only. These instruments included the Model 016-2 aspirated temperature/dew point shield, the Model CI-16 translator, Model A1554-3 dew point bridge circuit board with a range of 0.0 to +100°F (-18 to 38°C), and the Model 014-2 dewcell probe. The circuit includes a large capacitor for damping noise.

Optical condensation hygrometers obtain dew points by cooling a polished mirror surface until condensation occurs. The temperature of a thermometer embedded in the mirror surface is then measured. These instruments are capable of faster response and operation over a greater range of temperatures and dew points than other hygrometers designed for field use. A typical dew point range is -70 to +60°C. Instrument response is limited by the finite amount of time required to condense or evaporate a condensate film on the mirror surface (Reference 7). The cooling rate of the thermoelectric (Peltier) cooler is usually so rapid that its response time is not a limiting factor.

The General Eastern 1200 Dew Point and Temperature Monitoring System (GE No. 1, GE No. 2), and the EG&G Environmental Dew Point Temperature Monitoring System (EG&G) are optical condensation hygrometers which use aspirated platinum resistance thermometers mounted in thermal shields for temperature measurement. Dew points are obtained with thermometers or thermistors embedded in cooled mirrors. GE lists temperature system accuracy as 0.2°C, with a response lagged to 0.56°C per minute. The dew point system accuracy is 0.2°C, with a response of 1.7°C per second (Reference 10). The EG&G temperature sensor accuracy is listed at 0.4°C, with a time constant of 40 seconds. For the dew point, EG&G offers a nominal accuracy of 0.4°C, and a response time of 2.0°C per second (Reference 8).

Operator adjustments affecting the dynamic response of the cooled mirror dew point sensors include the GAIN, COMPENSATION, and THICKNESS. GAIN controls the system dynamic response. EG&G describes COMPENSATION as a phase lead to the amplifier circuit which compensates for the thermal phase-lag characteristic of the Peltier cooler (Reference 8). COMPENSATION dampens oscillations, allowing higher GAIN settings and improved dynamic performance. THICKNESS controls the thickness of film on the mirror. The THICKNESS adjustment represents a compromise between optimum dynamic response and insensitivity to contamination.

Response to mirror condensation is relatively fast at temperatures above -18°C, but at lower temperatures the minute amount of water present in the atmosphere requires a longer time to form the required condensate thickness on the mirror. Consequently, sampling duration must be increased for very cold temperatures. A second complication with operating condensation hygrometers at temperatures ranging from 0 to -30°C is that dew or frost may form on the mirror surface. A dew surface formed at these temperatures will eventually freeze. Hasegawa recommends that sufficient time be allowed for freezing to occur before a reading is taken (Reference 9). In addition to a relatively fast response time, the dew point mirror system can operate in a contaminated environment if the mirror surface is cleaned periodically.

Temperature measurements were also obtained through a Climet CI-60 translator with a Yellow Springs Instruments (YSI) thermilinear thermistor network and a YSI No. 44203 thermistor. Nominal accuracy is 0.15°C, with a time constant of 10 seconds in still air. The thermistor was mounted in a Climet shielded, aspirated temperature horn.

APPENDIX C. DATA

This appendix contains plots of temperature and dew point data for trials conducted on 5 May, 19 May, and 1 June 1981. Figures C.1 - C.24 depict temperature and dew point traces in 15-minute increments for each trial. The 5 May trial temperature data is presented in Figures C.1 - C.4, followed by dew point data in Figures C.5 - C.8. The 19 May and 1 June trials are covered in similar fashion by Figures C.9 - C.16 and C.17 - C.24. The plots were prepared from one-second averaged data. The time scale on each plot is compressed by a factor of 10.

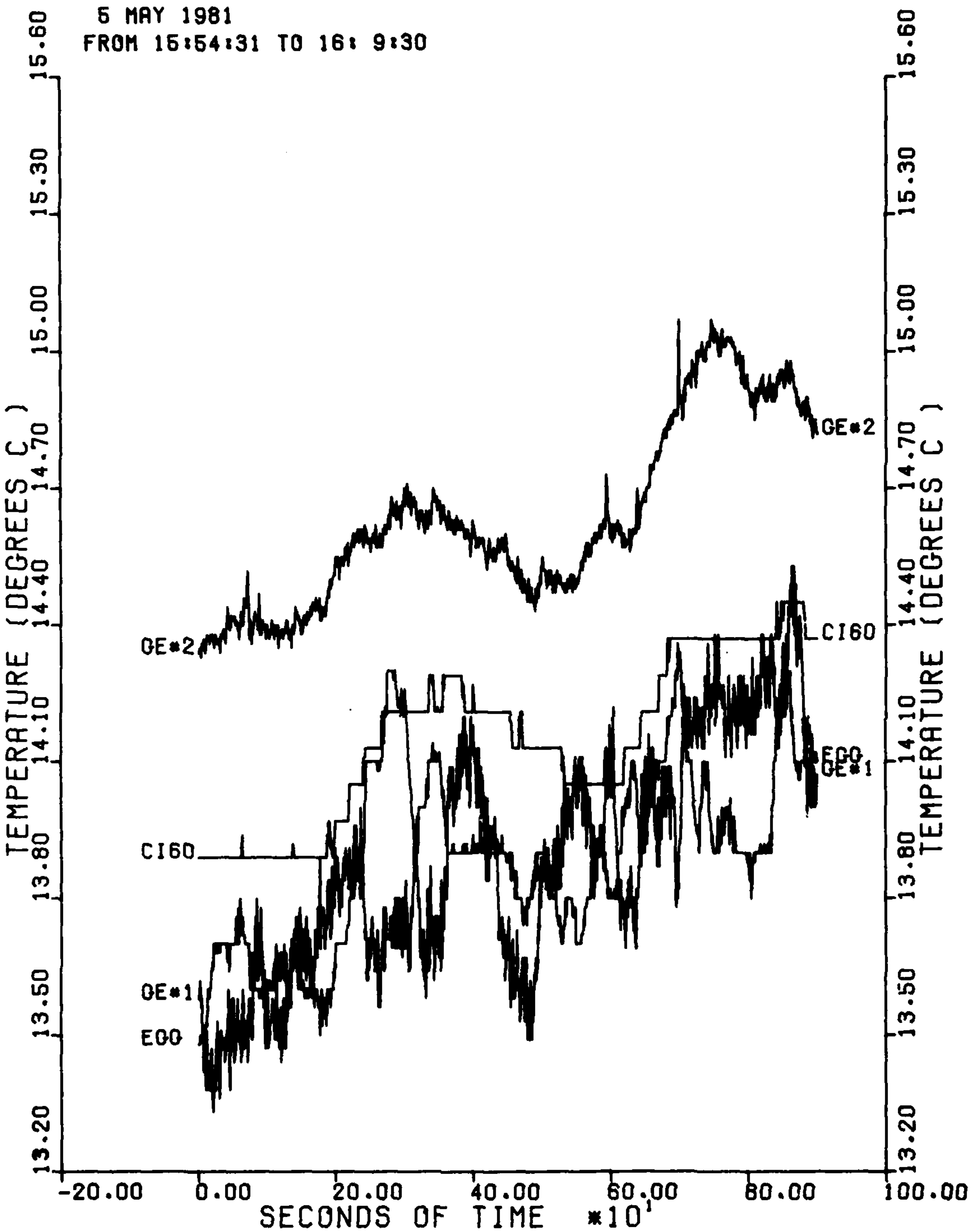


FIGURE C1. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

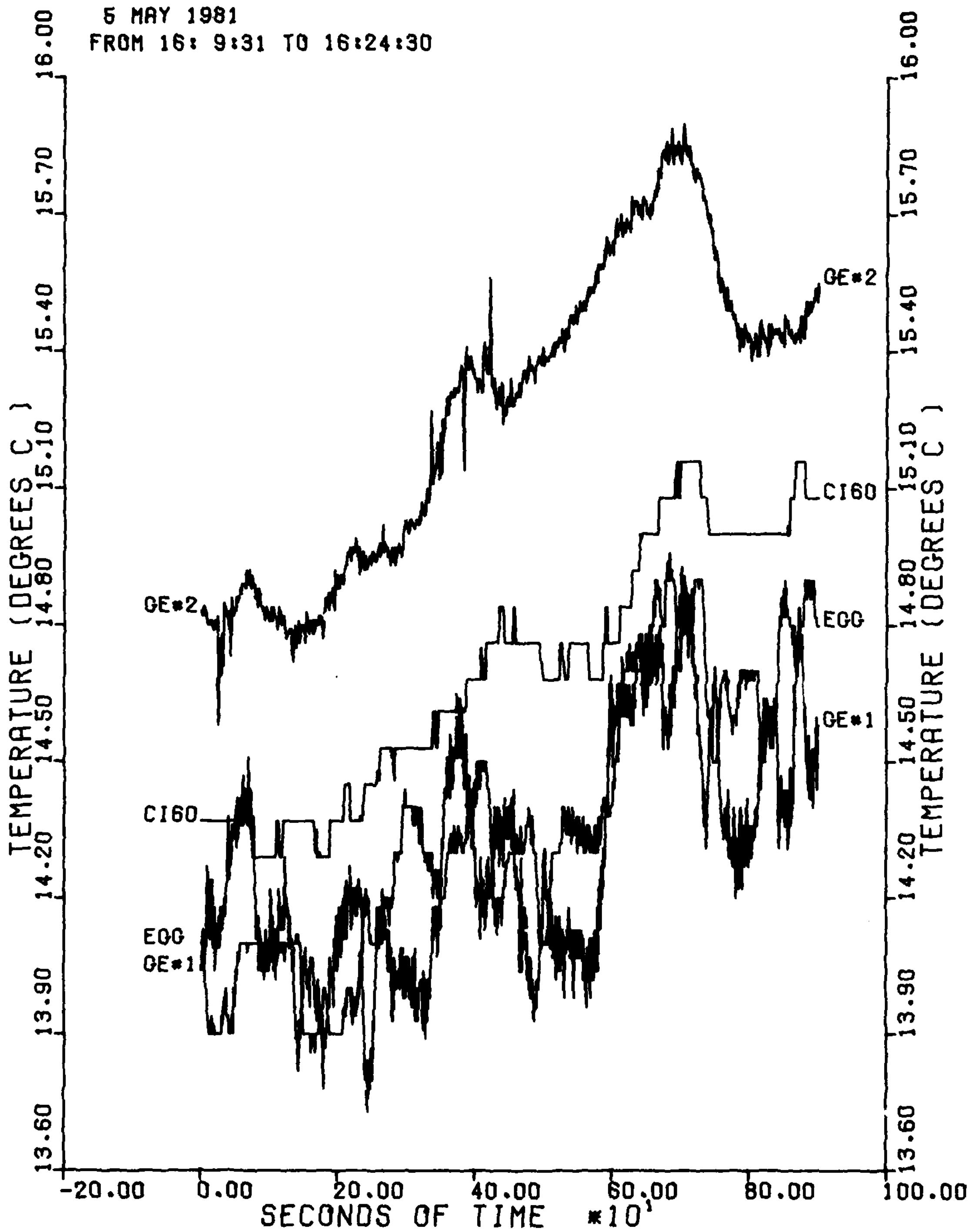


FIGURE C2. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

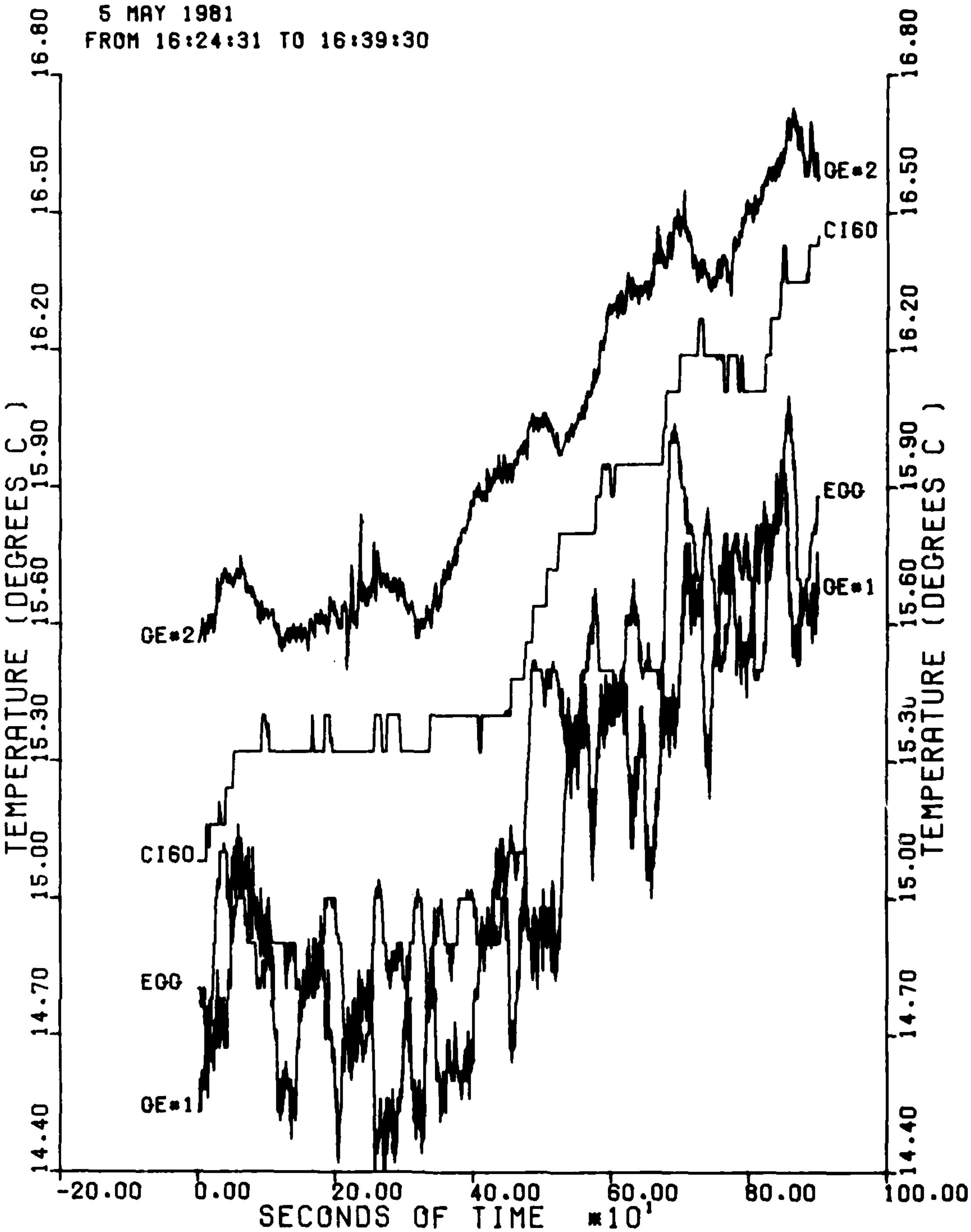


FIGURE C3. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

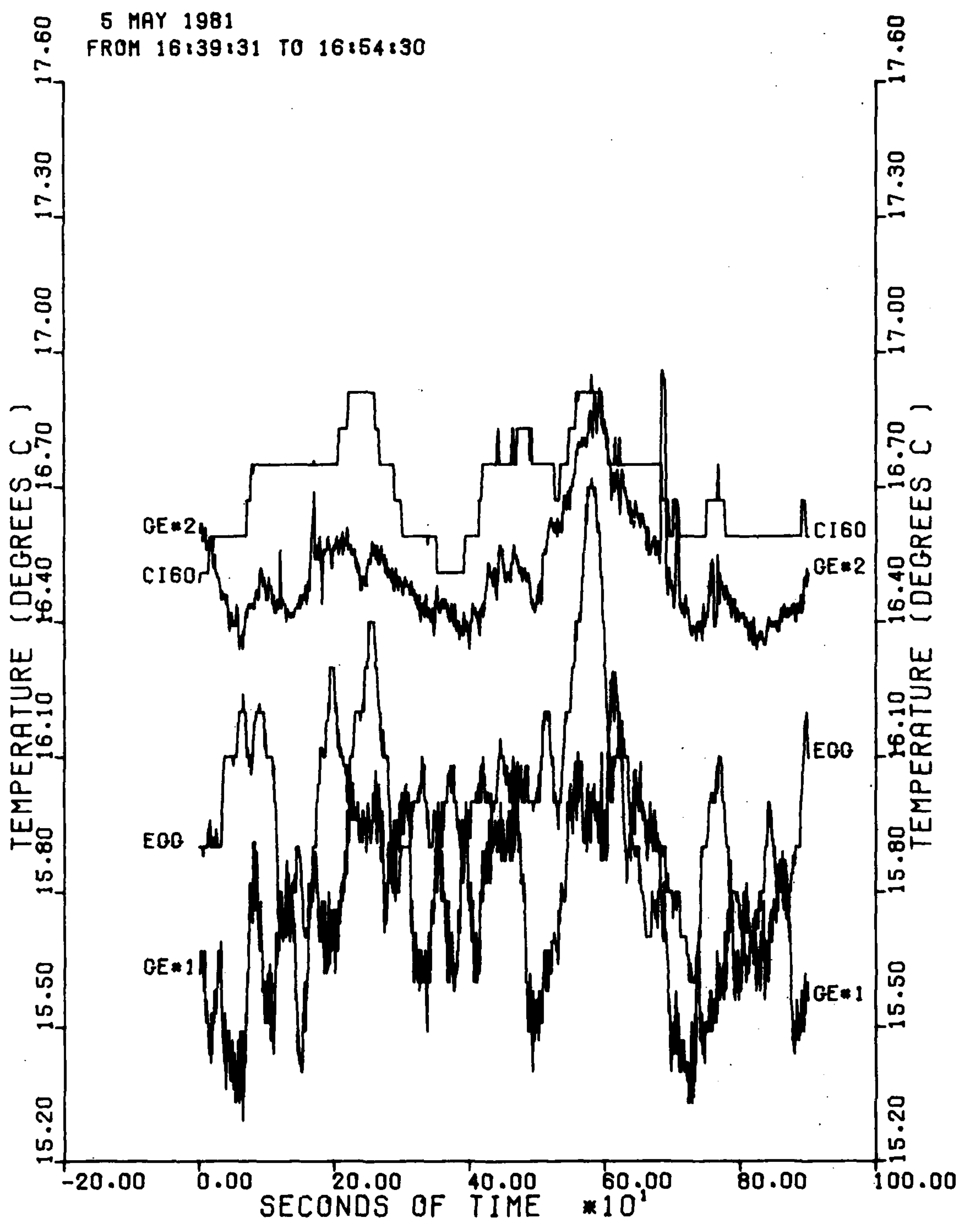


FIGURE C4. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

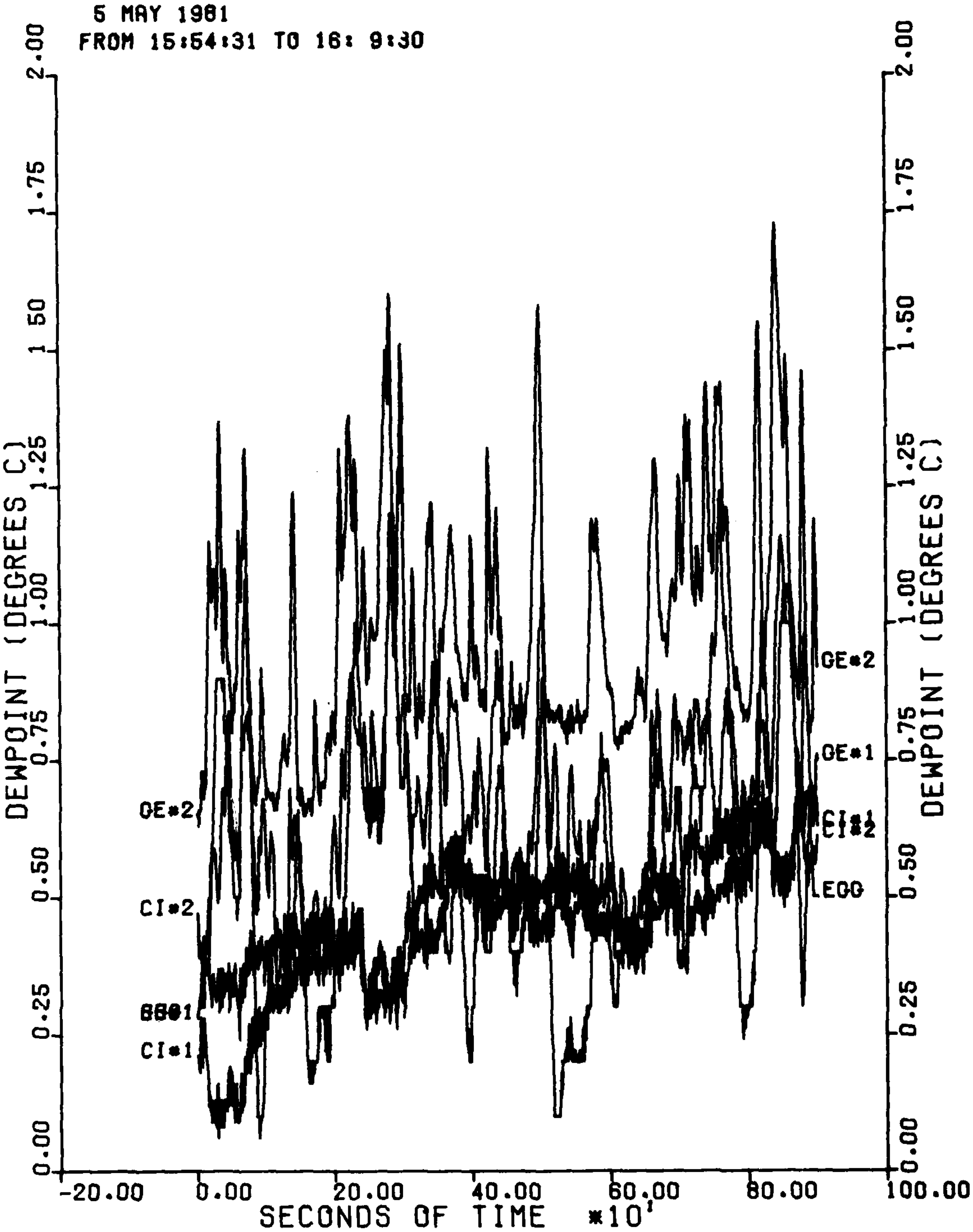


FIGURE C5. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

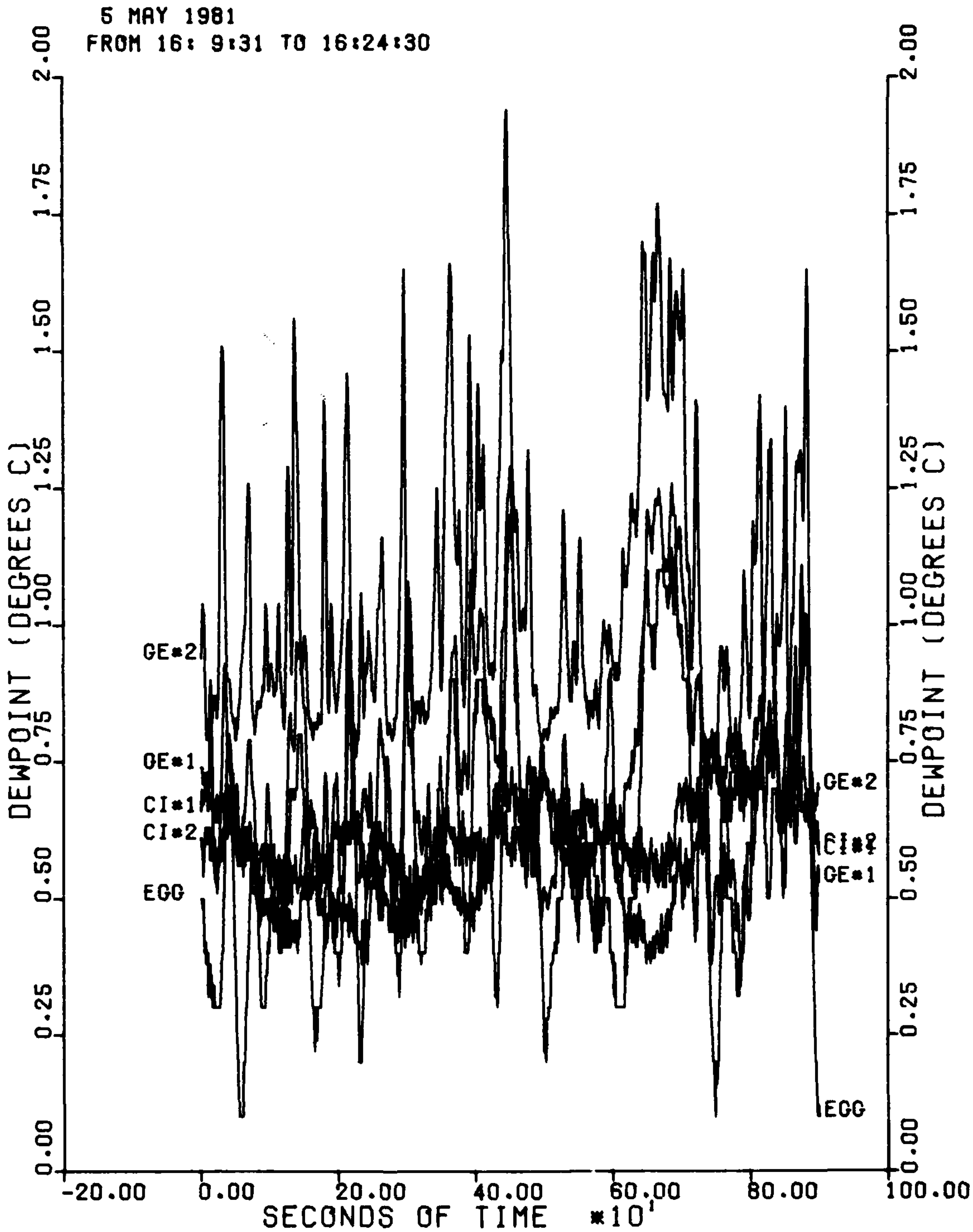


FIGURE C6. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

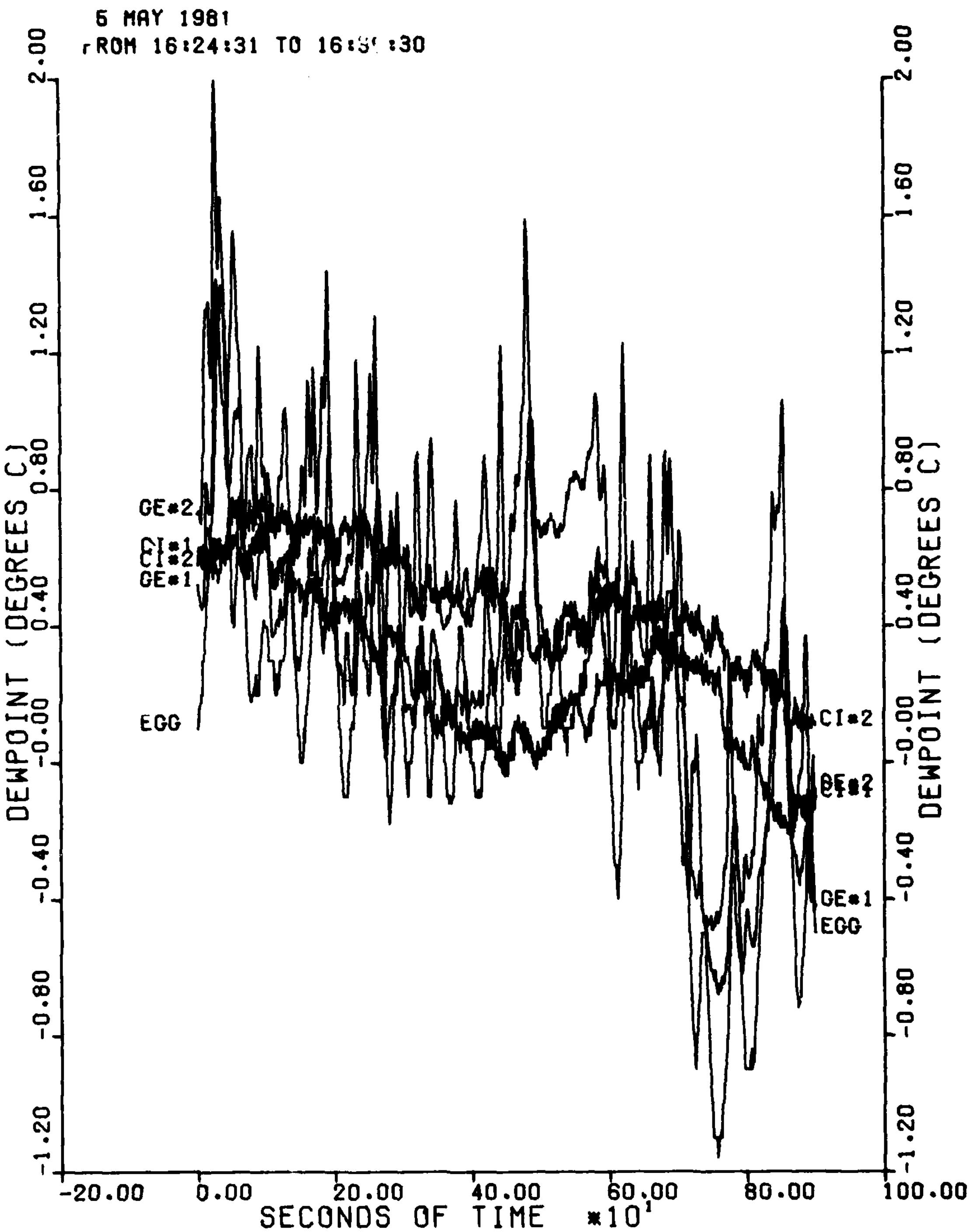


FIGURE C7. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

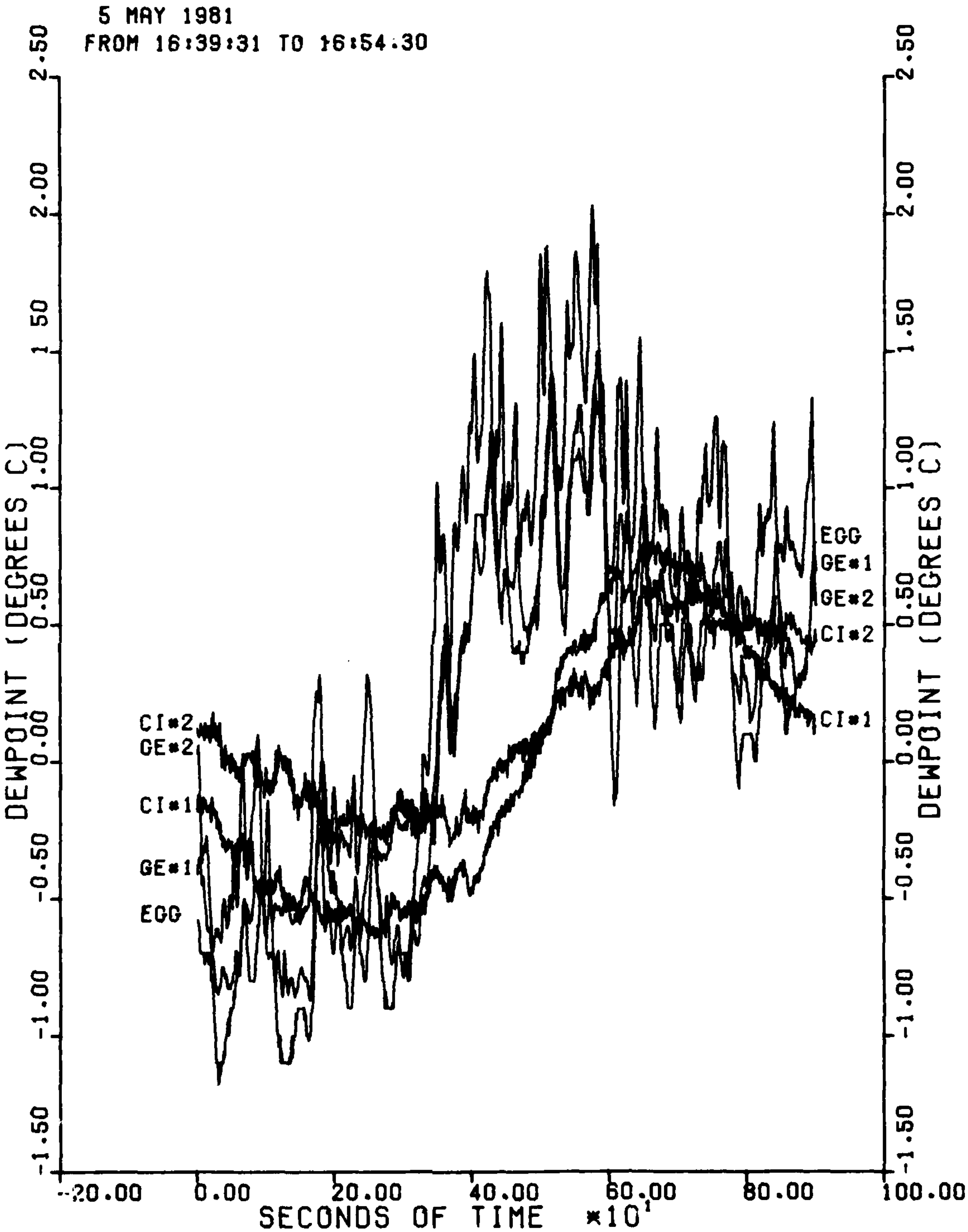


FIGURE C8. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

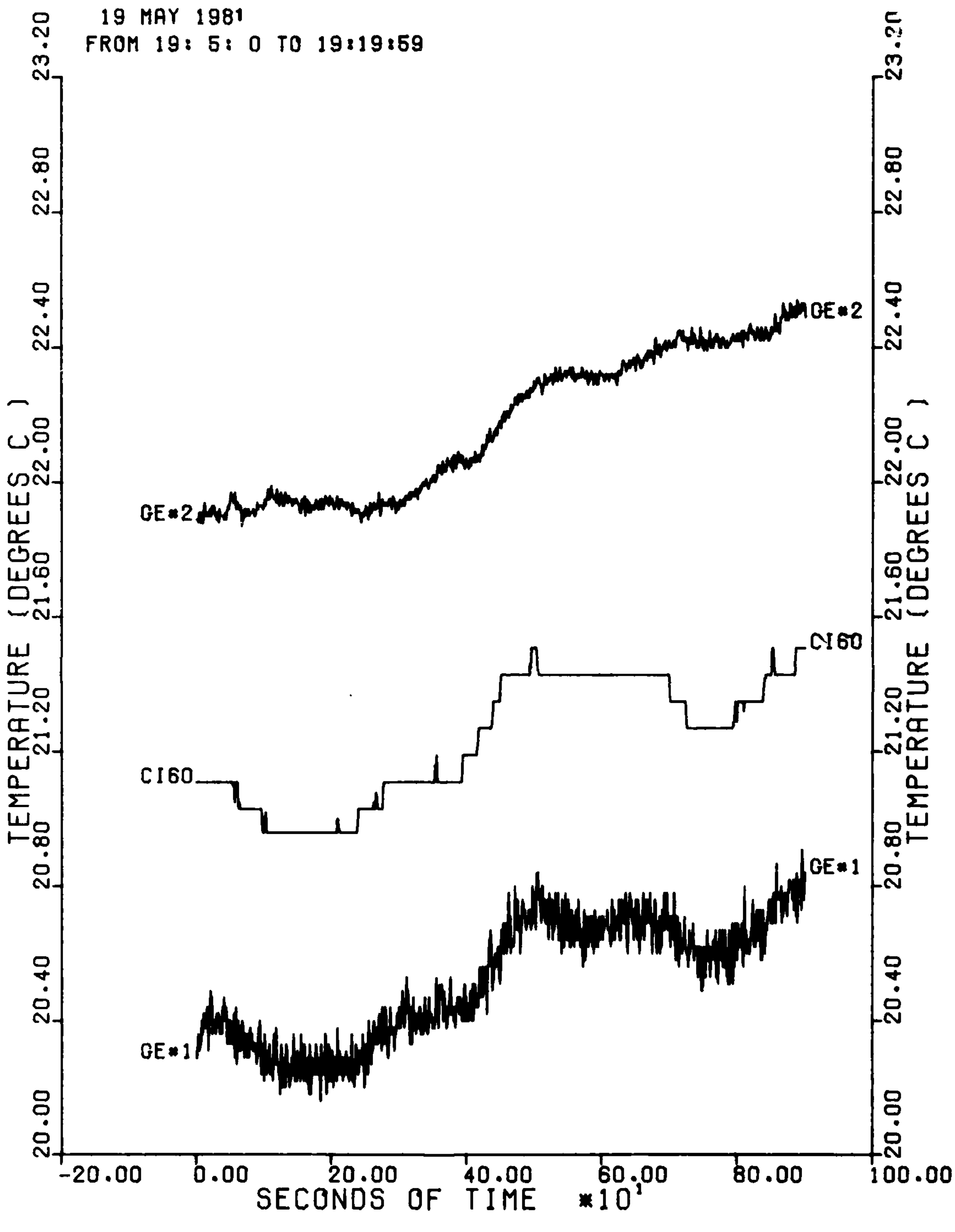


FIGURE C9. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

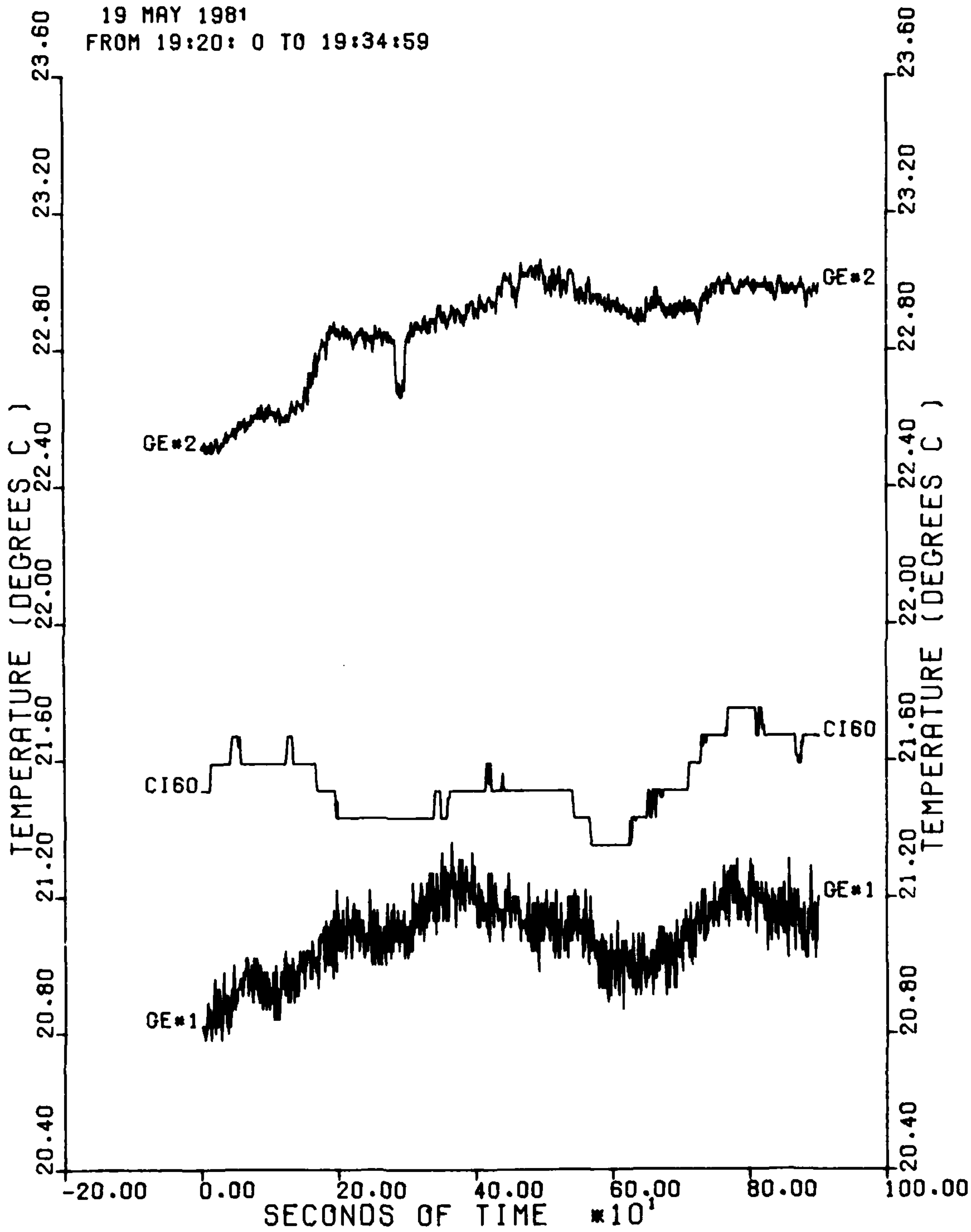


FIGURE C10. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

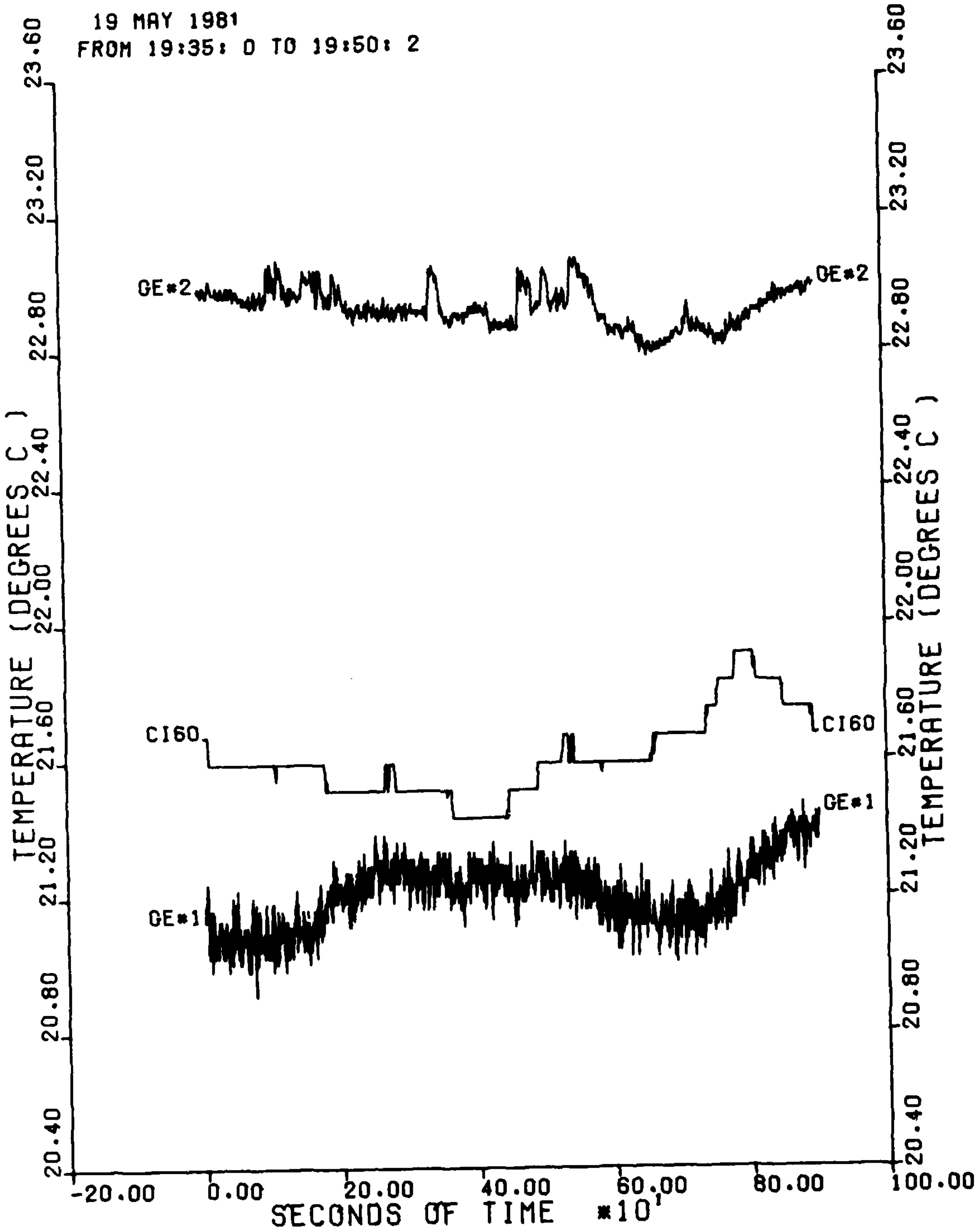


FIGURE C11. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

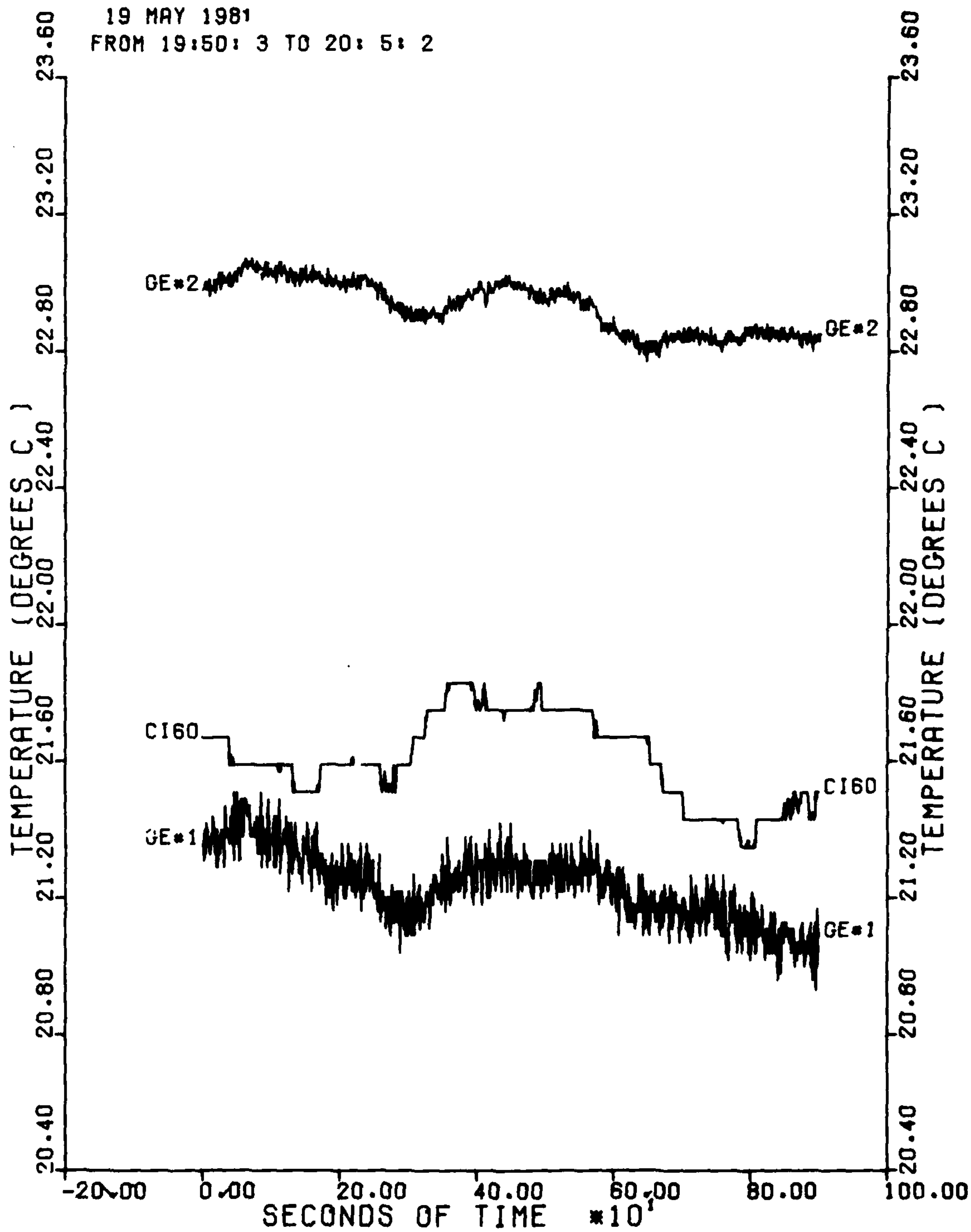


FIGURE C12. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

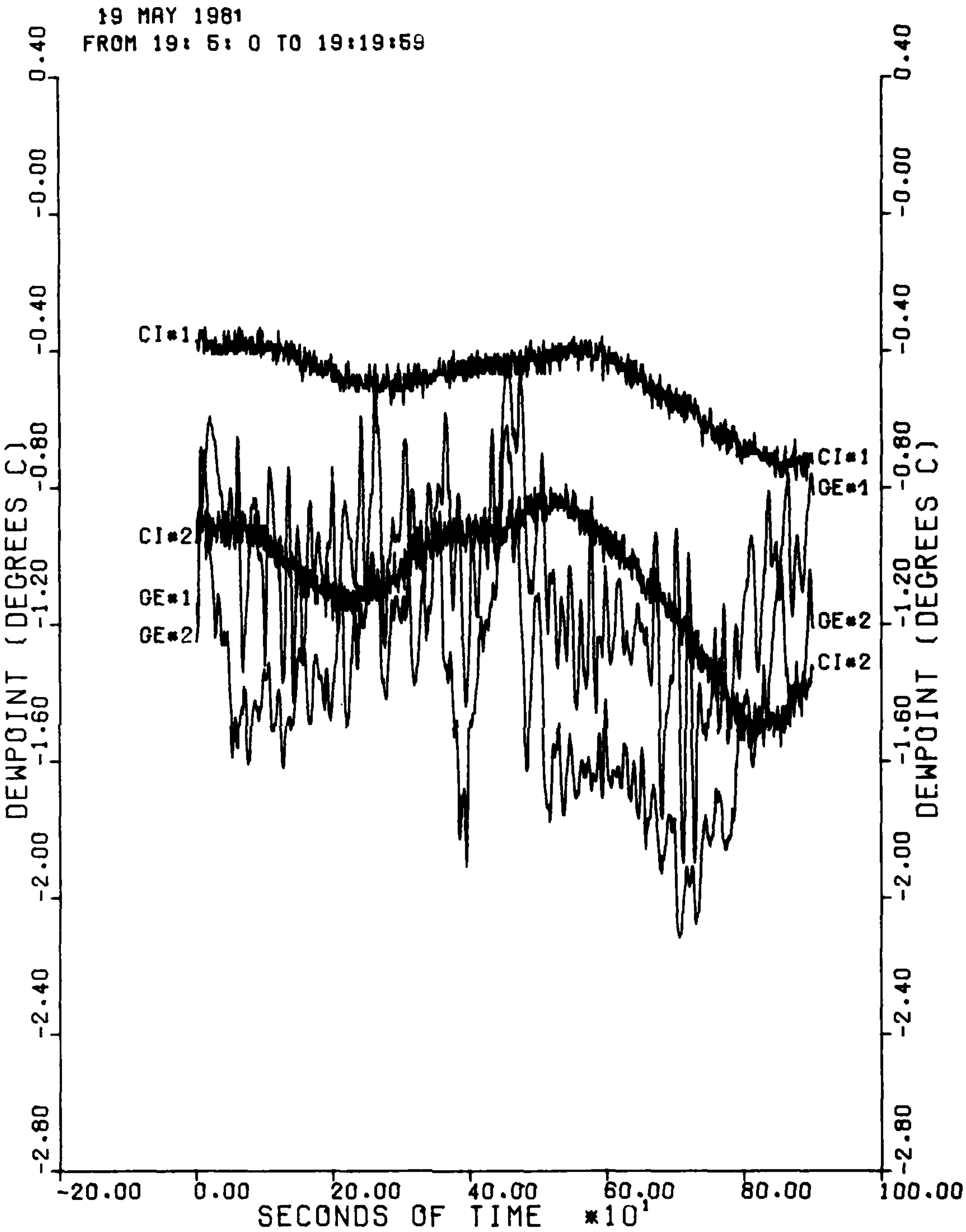


FIGURE C13. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

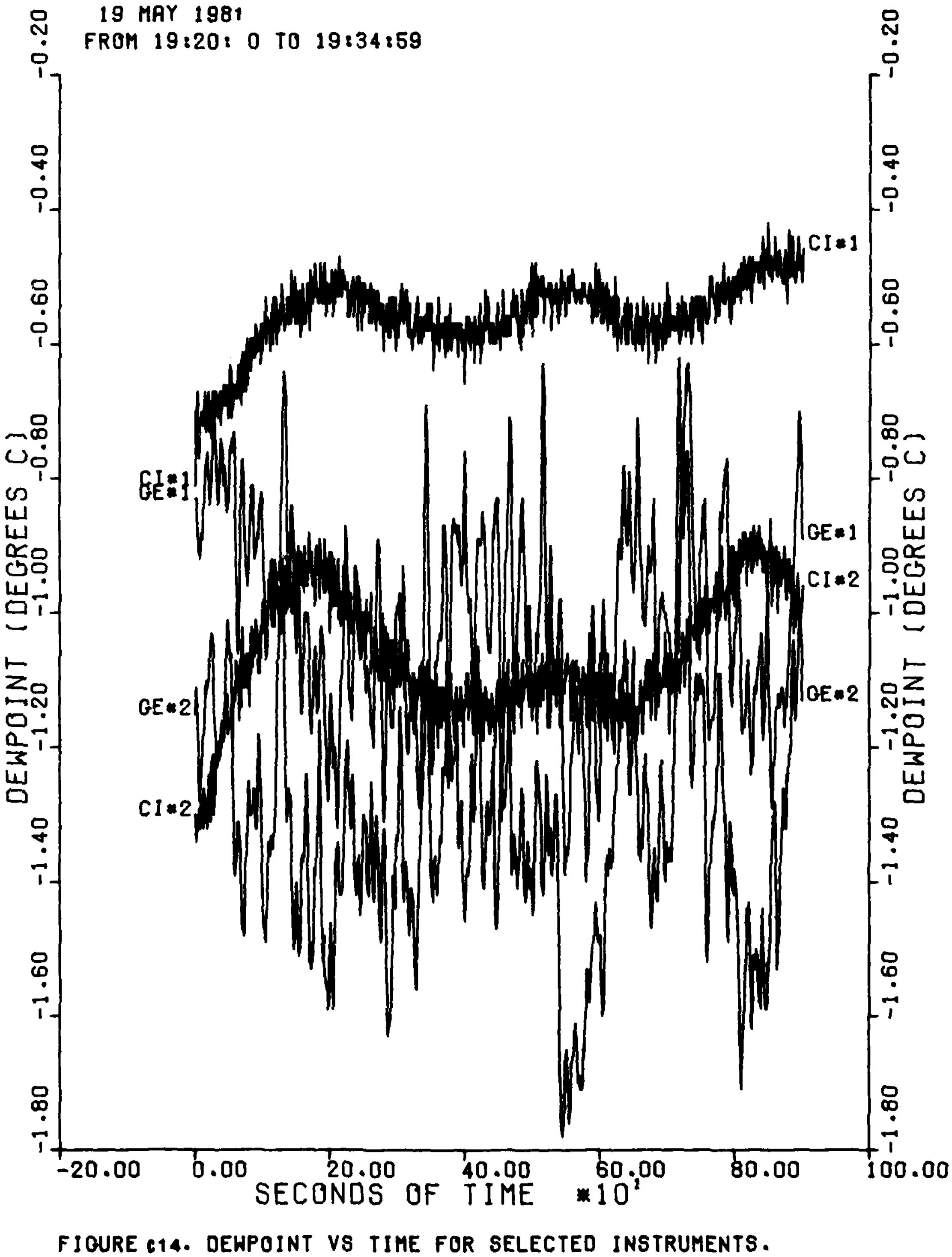


FIGURE C14. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

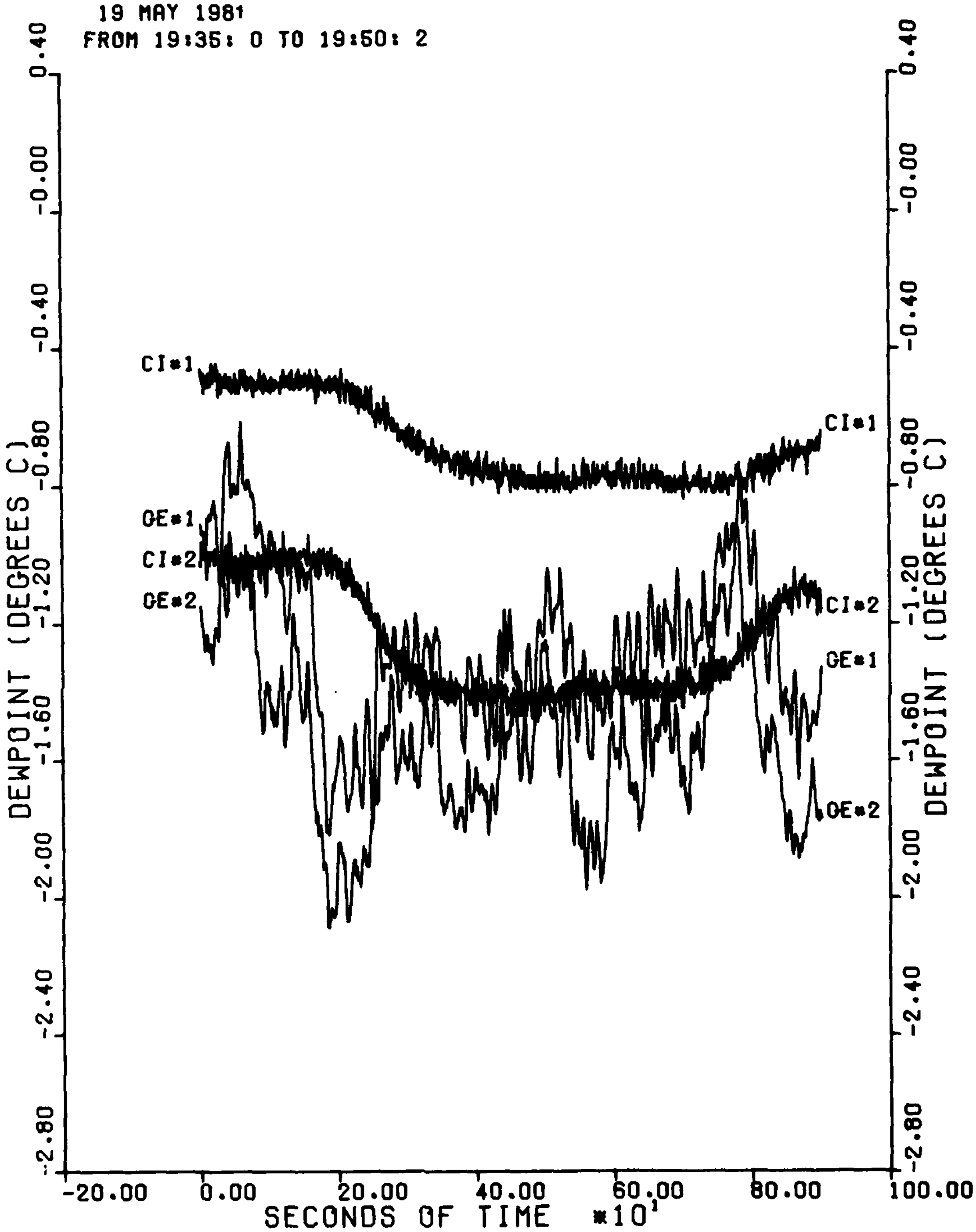


FIGURE C15. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

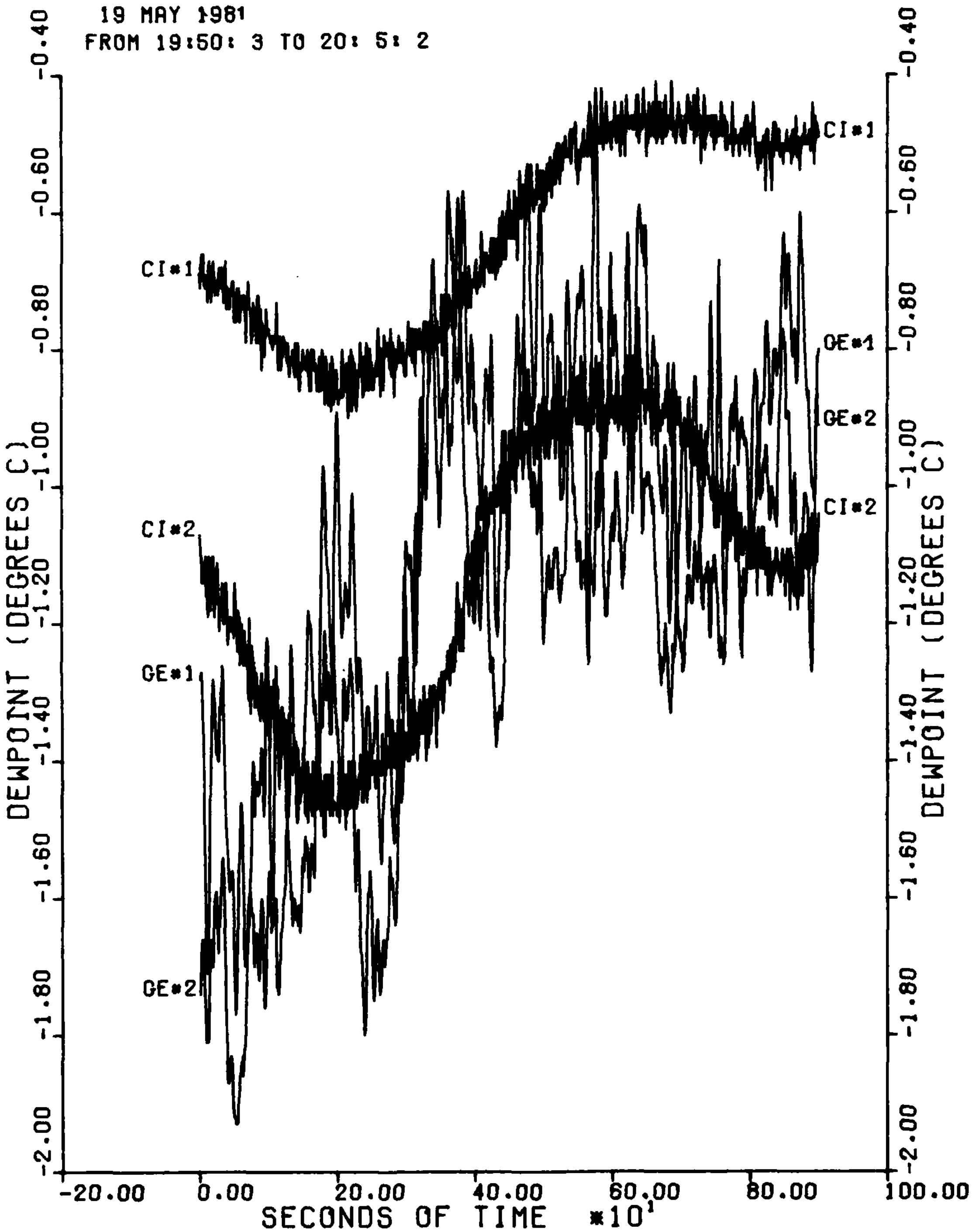
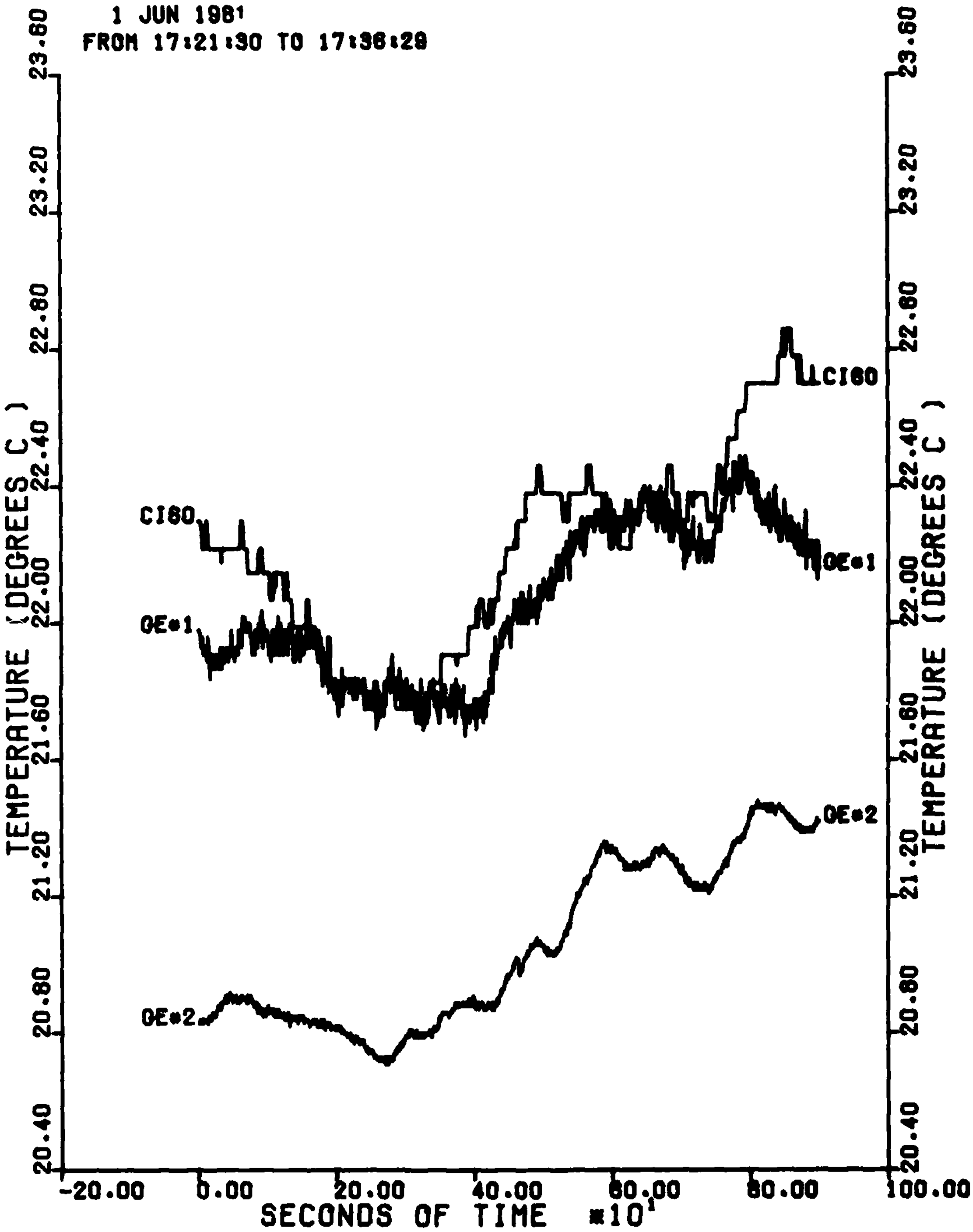


FIGURE C16. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.



FIGUREc17. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

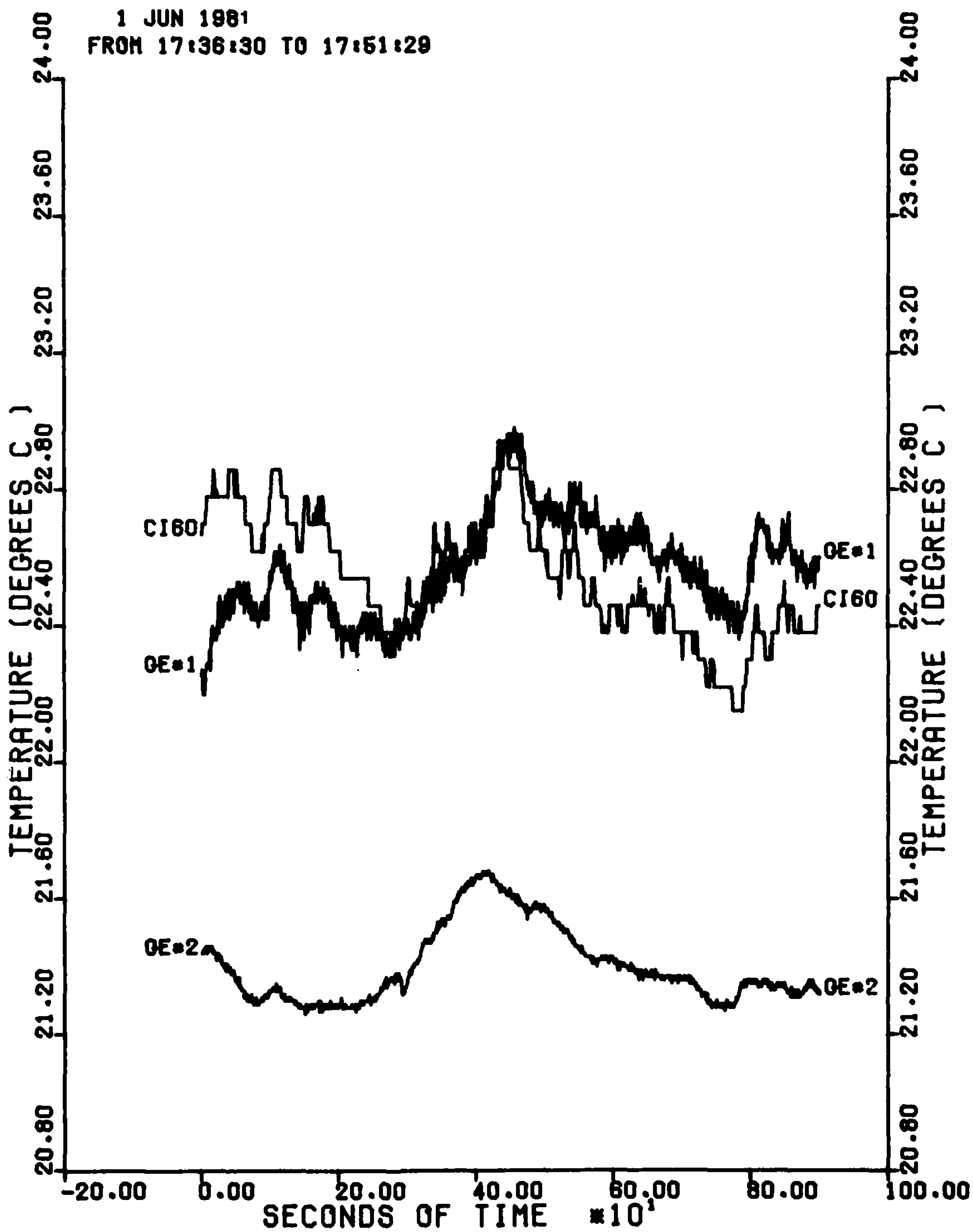


FIGURE C18. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

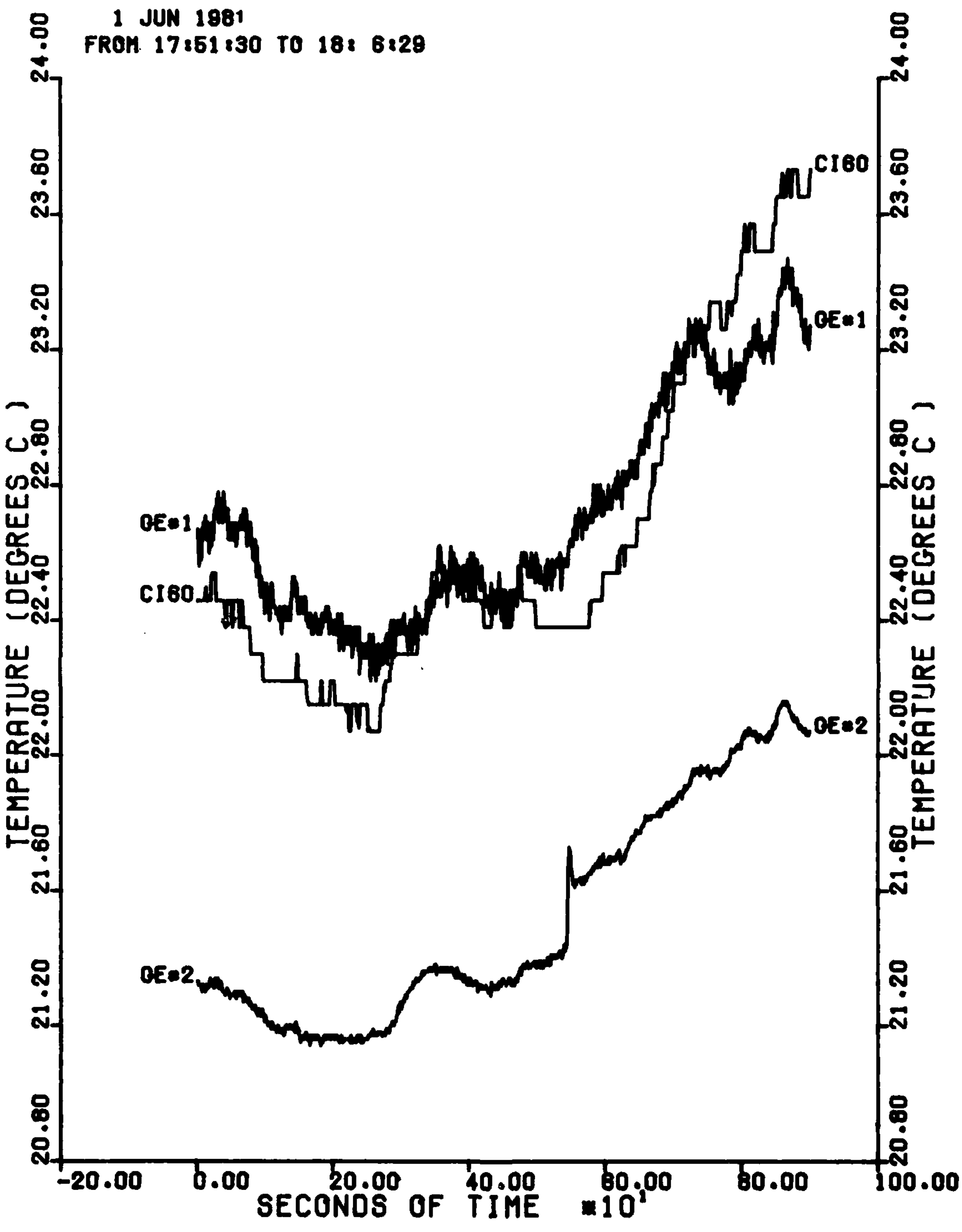


FIGURE C19. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

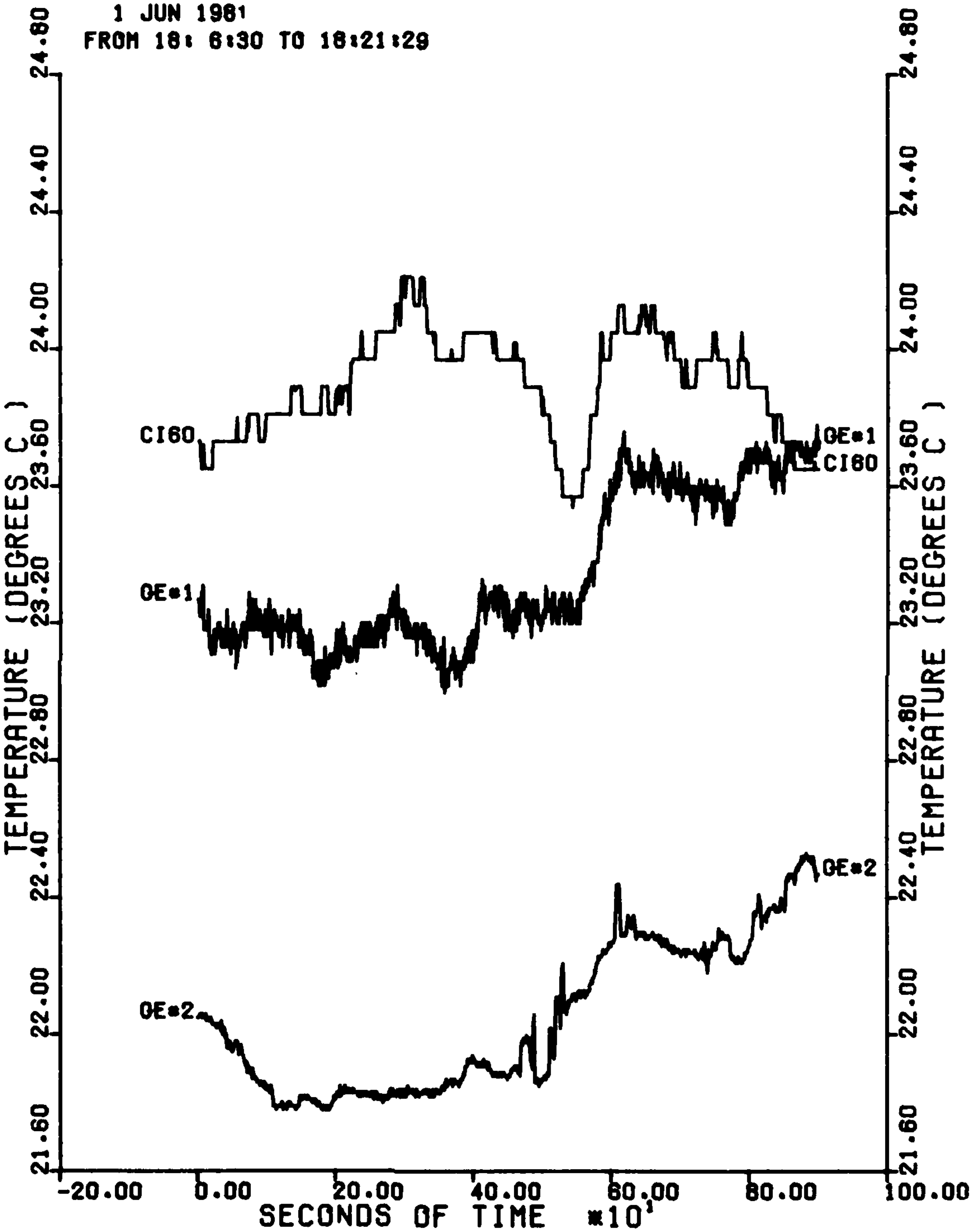


FIGURE C20. TEMPERATURE VS TIME FOR SELECTED INSTRUMENTS.

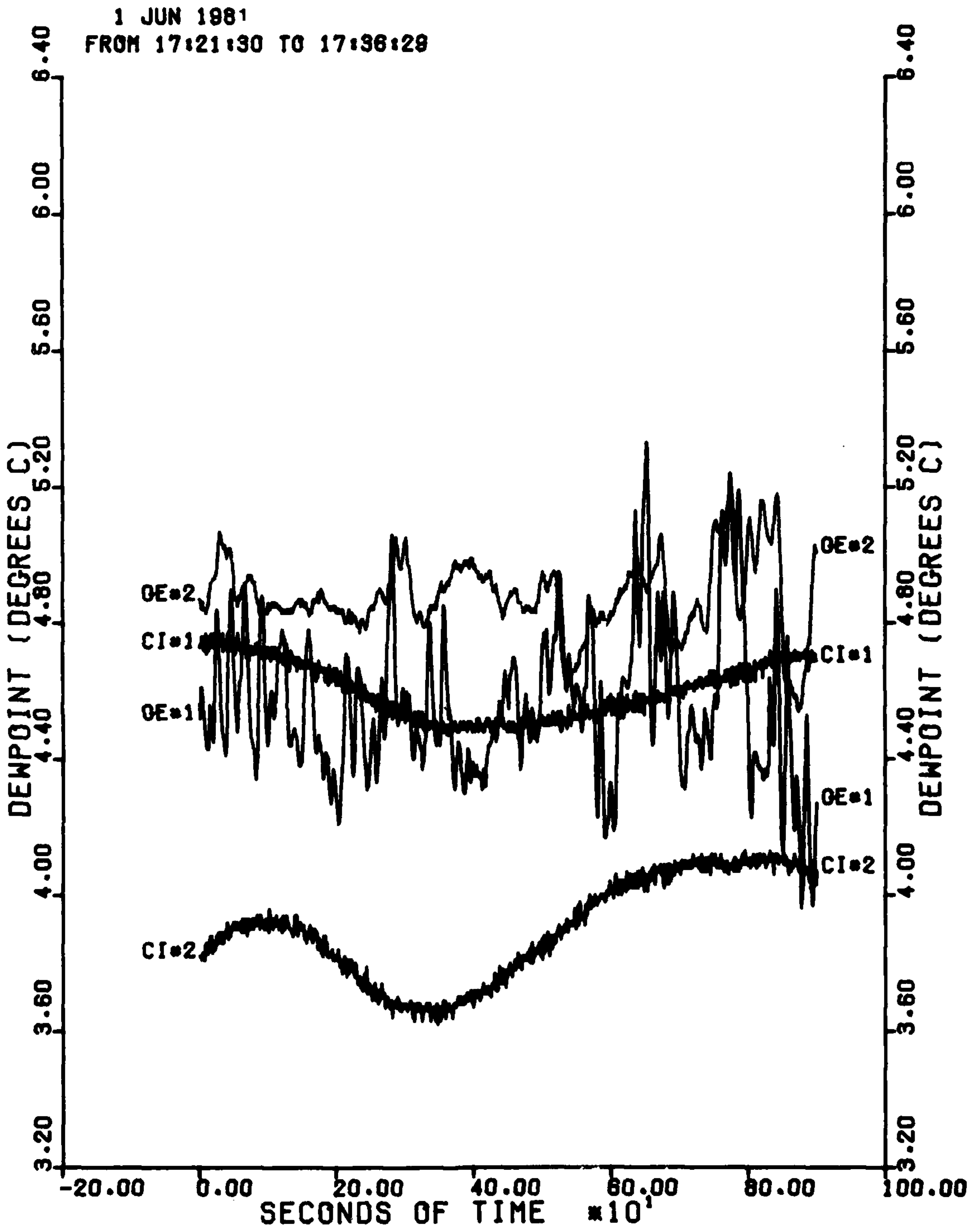
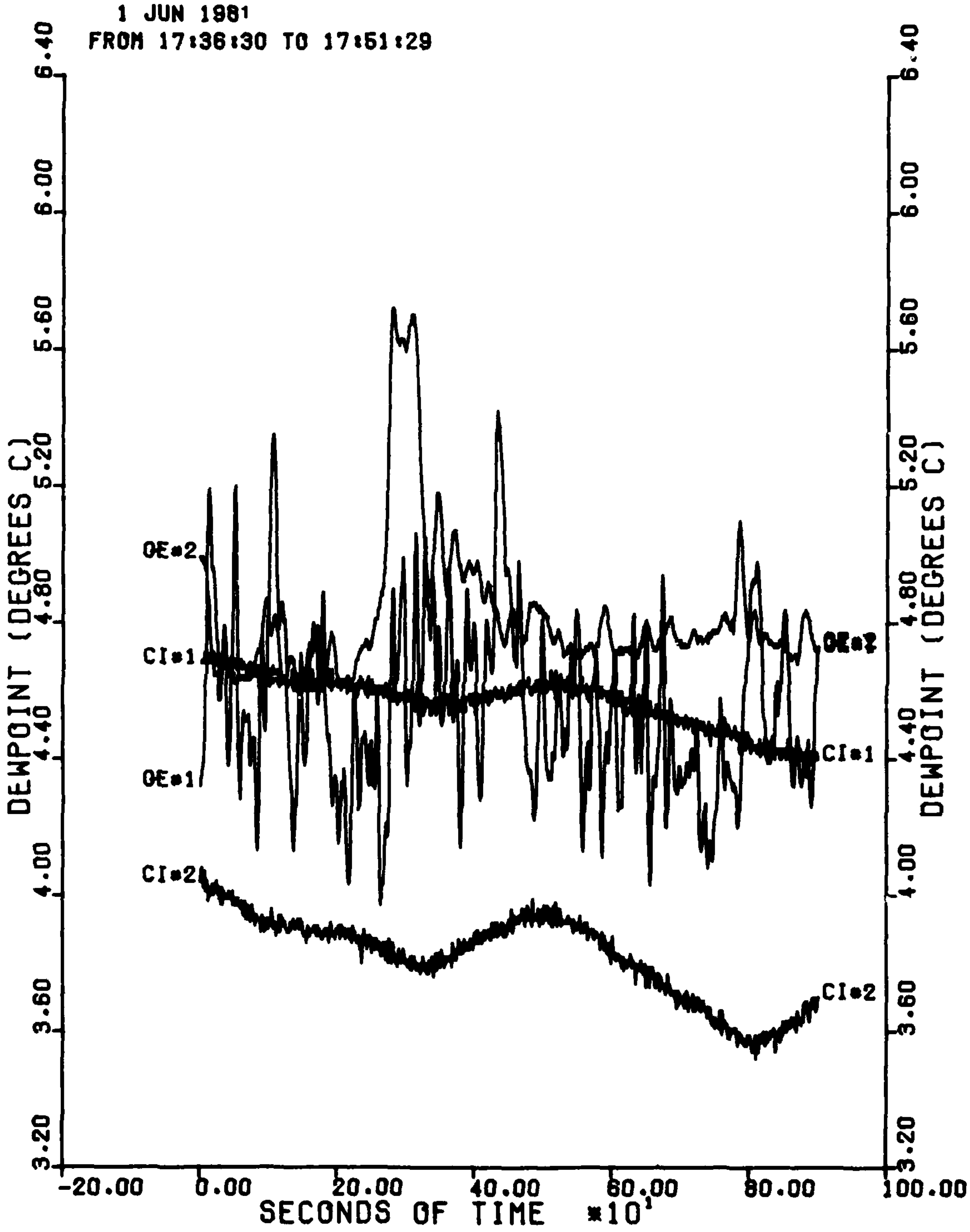


FIGURE C21. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.



FIGUREC2 2. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

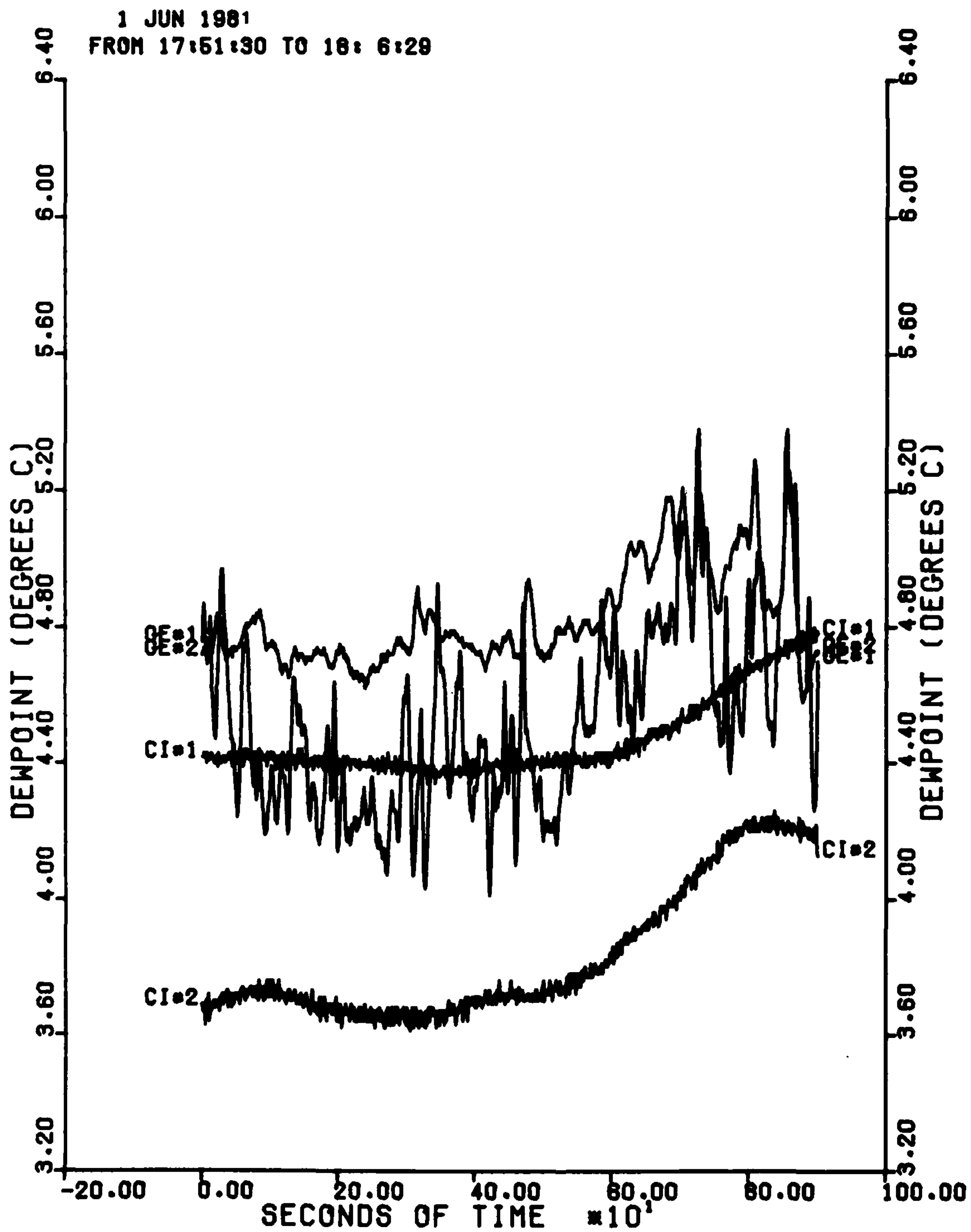


FIGURE C2 3. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

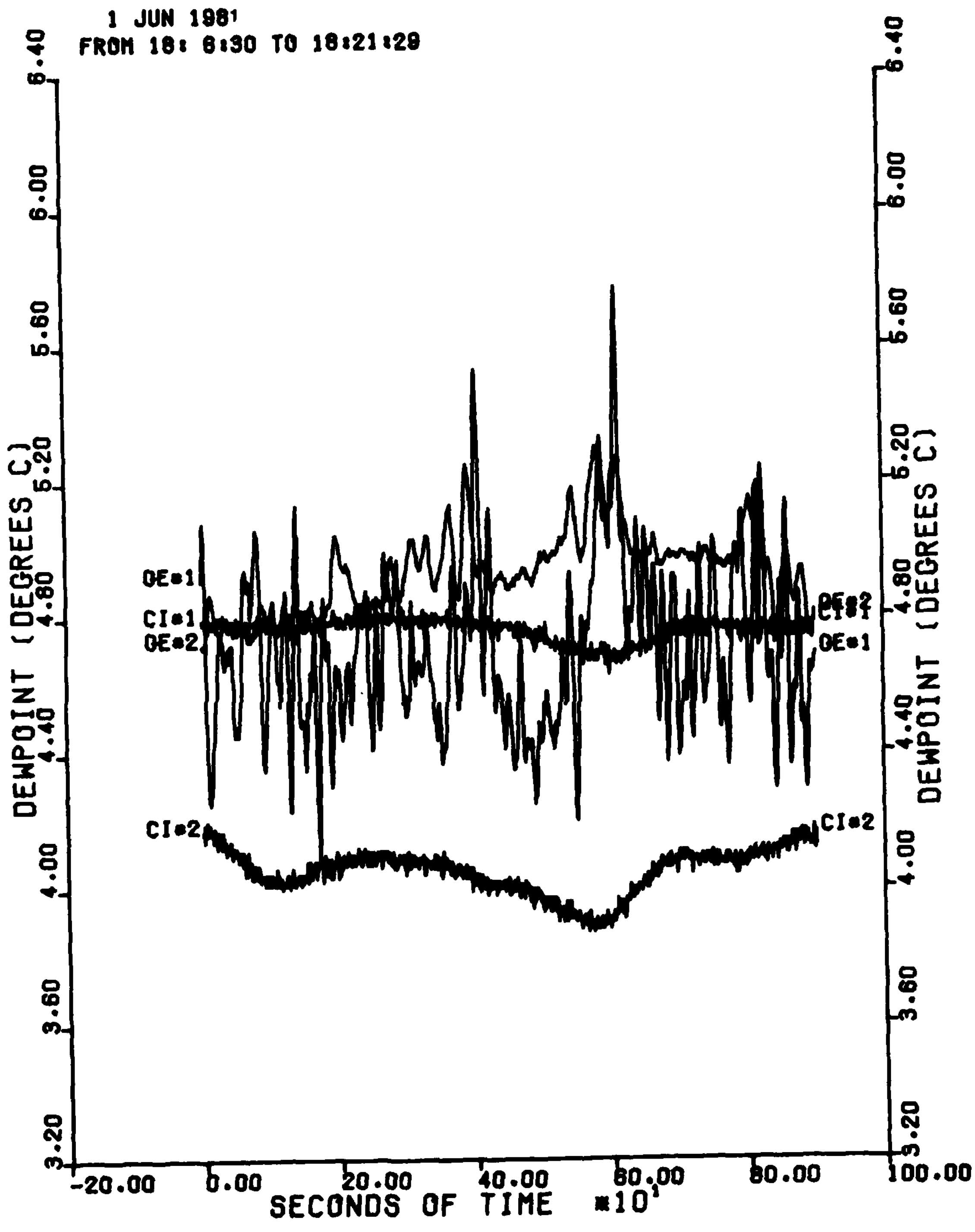


FIGURE C24. DEWPOINT VS TIME FOR SELECTED INSTRUMENTS.

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